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U.S. DEPARTMENT OF COMMERCE
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SUMMARY

The spawning biomass of the Pacific sardine (*Sardinops sagax*) in April 2011 was estimated using the daily egg production method (DEPM) calculated by two methods: 1) the traditional method where the egg production (P_0) was a weighted mean while each adult parameter was an unstratified estimate, and 2) a stratified procedure where the estimate of total spawning biomass is the sum of the estimated spawning biomass in each of two regions representing high and low spawning activity. The two estimates of the spawning biomass were 383,286 mt (CV = 0.32) and 373,348 mt (CV = 0.28), respectively, for the standard DEPM survey area of 314,480.69 km^2 off the west coast of North America from San Diego, California to north of San Francisco, California (CalCOFI line 60.0-95.0). The daily egg production estimate (P_0, a weighted average with area as the weight) was 1.16/.05m^2 (CV = 0.26). In the standard DEPM area, the estimates of female spawning biomass calculated by the two methods were 225,155 mt (CV = 0.32) and 219,386 mt (CV = 0.28), respectively. A small region close to Astoria, Oregon (47.1° - 45.9°N) was sampled for sardines. No eggs and only 2 immature sardine were collected in this area. Hence, coastwide estimates of sardine spawning biomass and female spawning biomass were not calculated.

The estimated daily specific fecundity was 19.04 (number of eggs/population weight (g)/day) using the following estimates of reproductive parameters from 244 mature female Pacific sardines collected from 30 positive trawls: *F*, mean batch fecundity, 38,369 eggs/batch (CV = 0.07); *S*, fraction spawning per day, 0.1078 females spawning per day (CV = 0.18); W_f, mean female fish weight, 127.6 g (CV = 0.05); and *R*, sex ratio of females by weight, 0.587 (CV = 0.06). Since 2005, trawling has been conducted randomly or at CalCOFI stations, which resulted in sampling adult sardines in both high (Region 1) and low (Region 2) sardine egg-density areas. During the 2011 survey, the number of tows positive for mature female sardines was similar in Regions 1 and 2 (14 and 16 respectively), while four tows in Region 2 contained solely immature sardines.

The estimates of spawning biomass of the Pacific sardine off California in 1994 – 2011 based on the traditional method are: 127,000 mt, 80,000 mt, 83,000 mt, 410,000 mt, 314,000 mt, 282,000 mt, 1.06 million mt, 791,000 mt, 206,000 mt, 485,000 mt, 300,000 mt, 600,000 mt, 837,000 mt, 392,000 mt, 117,000 mt, 185,000, 108,000mt and 383,000 mt (for the standard DEPM area), respectively. These estimates of spawning biomass indicate that there has been considerable fluctuation during this time (the peaks occurred in 2000 and 2006) and that biomass has declined in 2008-2010 and increased in 2011. The time series of spawning biomass was one of the fishery-independent inputs to the annual stock assessment of the Pacific sardine from 1985 – 2008. Since 2009, the time series of spawning biomass was replaced by female spawning biomass for years when sufficient trawl samples were available and the total egg production for other years as inputs to the stock assessment of Pacific sardines.

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INTRODUCTION

The spawning biomass of the Pacific sardine (*Sardinops sagax*) was estimated using the daily egg production method (DEPM: Lasker 1985) in 1986 (Scannel et al. 1996), 1987 (Wolf 1988a), 1988 (Wolf 1988b), 1994 (Lo et al. 1996), and 1996 (Barnes et al. 1997). The DEPM estimates spawning biomass by 1) calculating the daily egg production from ichthyoplankton survey data, 2) estimating the reproductive parameters of females from adult fish samples, and 3) calculating the biomass of spawning adults. Before 1996, sardine egg production was estimated from CalVET plankton net samples. Adult fish were sampled in various ways prior to 1996 to obtain specimens for batch fecundity, spawning fraction, sex ratio, and average female fish weight (Wolf 1988a, 1988b; Scannell et al. 1996; Macewicz et al. 1996; Lo et al. 1996).

Since 1996, in addition to CalVET and Bongo nets, the Continuous Underway Fish Egg Sampler (CUFES; Checkley, et al. 1997) has been used as a routine sampler for fish eggs, and data on sardine eggs collected with CUFES have been incorporated in various ways into the estimation procedures for daily egg production. In the 1997 sardine egg survey (Hill et al. 1998, Lo et al. 2001), CUFES was used to allocate CalVET tows in an adaptive sampling plan. From 1998 to 2000, data on sardine eggs collected with both CalVET and CUFES during each April California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise were used to estimate daily egg production (Hill et al. 1999). Use of the full data sets from both samplers in the DEPM can be time consuming. Furthermore, the CUFES samples are exclusively from 3 m depth and it is not clear whether sardine egg stages from CUFES samples are representative of the entire vertical distribution of stages. Use of the CUFES data also requires an estimated conversion factor from eggs/min to eggs/0.05m^2. Starting with the 1999 April CalCOFI survey, an adaptive allocation survey design similar to the 1997 survey was implemented. In this design, CalVET tows are added in areas where they were not pre-assigned if sardine egg densities in CUFES collections exceeded a threshold value, e.g., 1 egg/minute.

Since 2001, a cost-effective alternative has been adopted to calculate the DEPM index that reduces effort in calculation and egg staging of the CUFES collections. This revised DEPM index only uses CalVET samples of eggs and yolk-sac larvae and Bongo samples of yolk-sac larvae, all from the high density area (Region 1), to provide an estimate of P_0, the variance of which may be large due to small sample size (fewer than 100 plankton tows in some years). Adult samples were collected sporadically in 1997, 2001, and 2002 (Lo et al. 2005).

Starting in 2004, full-scale surveys have been conducted for collection of Pacific sardine eggs, larvae, and adults to better estimate the spawning biomass in the area off California between San Diego and San Francisco (Lo and Macewicz 2004; Lo et al. 2005; Lo and Macewicz 2006; Hill et al. 2006 a, b; Lo et al. 2007a, b, 2008, Lo et al. 2009, 2010b). In 2004 the adult samples were taken primarily in the high density area, but beginning in 2005 adult Pacific sardine samples for reproductive output were taken in both high and low sardine egg density areas. The ichthyoplankton samples taken during regular April CalCOFI cruises were also included in the spawning biomass computation. During 2006, 2008 and 2010, the survey area was extended north to the US-Canadian border, and spawning biomass was computed for both the whole survey area and the standard DEPM survey area, (from San Diego to San

Francisco). For 2011, even though eggs and adults were observed in the area between CalCOFI line 62.2 and 91.7, the daily egg production (P_0) was estimated for the standard DEPM survey area between CalCOFI lines 60.0 and 95.0.

Since 2009, in addition to the estimates of spawning biomass based on the past procedure where P_0 was weighted by the size (km^2) of each region and the adult parameters were estimated from all trawl samples in the entire survey area, an alternative estimator based on stratified sampling for each parameter was also included (Hill et al. 2009) for years when adequate adult samples were available (1986, 1987, 1994, 2004, 2005, 2007 – present). As such, the original time series of spawning biomass may not be comparable due to slightly different estimation procedures and the refined survey designs over time. This alternative method was also used to estimate the female spawning biomass that is now used as a data time series for stock assessment computations. Here, we report the time series of spawning biomass, female spawning biomass, and total egg production based on both the traditional method and the stratified estimation procedure.

MATERIALS AND METHODS

Data

The spring 2011 California Current Ecosystem (CCE) survey was conducted aboard one NOAA research vessel and a chartered fishing vessel. The NOAA ship *Bell M. Shimada* (March 23-April 27) covered the area off of the west coast of US from Cape Flattery, Washington to San Diego, California with most of the stations off California located within the area from San Francisco to San Diego (CalCOFI lines 63.3 to 93.3 from March 27 to April 25). The F/V *Frosti* (March 26-April 28) covered the area from San Francisco to San Diego, California (CalCOFI lines 61.7 to 95, data collected April 1-26). Within the CCE survey the *Shimada* occupied the primary CalCOFI lines, 76.7 to 93.3, from April 10 to 25 for the spring CalCOFI cruise. During the CCE and the CalCOFI surveys, CalVET tows, Bongo tows, CUFES and trawls were conducted aboard both vessels. Data from both CCE and CalCOFI surveys were included in the estimation of spawning biomass of Pacific sardines.

In addition to sardine eggs and yolk-sac larvae collected with the CalVET net, yolk-sac larvae collected with the Bongo net have been included to model the sardine embryonic mortality curve since 2000. Beginning in 2001 (Lo 2001), CUFES data from the ichthyoplankton surveys have been used only to map the spatial distribution of the sardine spawning population with the survey area post-stratified into high-density (Region 1) and low-density (Region 2) areas according to the sardine egg density from CUFES collections. Staged eggs from CalVET tows and yolk-sac larvae from CalVET and Bongo tows in the high-density area have been used to model embryonic mortality in the high density area and the daily egg production, P_0, for the whole survey area.

During the 2011 CCE survey, twenty six distinct transects were occupied by the vessels. The *Shimada* occupied 13 out of 36 planned lines and the *Frosti* occupied 14 lines. CalCOFI line 76.7 was occupied once by the *Frosti* sampling with CUFES and trawls and then again by

Shimada during the April CalCOFI survey using the standard sampling protocol of ichthyoplankton tows and trawling. For the CCE survey, CalVET tows were taken at 4-nm intervals on each line after the egg density from each of two consecutive CUFES samples exceeded 1 egg/min, and CalVET tows were stopped after the egg density from each of two consecutive CUFES samples was less than 1 egg/min. The threshold of 1 egg/min was reduced from the number used in years prior to 2002 (2 eggs/min) to increase the area identified as the high-density area and, subsequently, to increase the number of CalVET samples. One egg/min is equivalent to two to thirteen eggs/CalVET tow, depending on the degree of water mixing. This adaptive allocation sampling was similar to that used in the 1997 survey (Lo et al. 2001). Because the threshold changed in 2002, caution should be taken when comparing the size of the area of Region 1.

In 2011, the entire survey area (314,481 km^2) was mostly south of CalCOFI line 60.0 (line 61.7 was the northern line occupied by *Frosti*) and was larger than the area in 2010 (271,773 km^2) south of CalCOFI line 60.0 (37.94°N latitude). This area, defined as the standard DEPM survey area, was used to estimate the initial P_0, even though no eggs were observed north of CalCOFI line 63.3, only two CUFES collections included sardine eggs near south of CalCOFI line 63.3 (63.1 and 63.2 aboard *Shimada*) and few eggs were collected southe of Calcofi line 86.7. The area between CalCOFI line 63.3 and 86.7 is termed the sub-DEPM area. The standard DEPM area was post-stratified into two regions: Region 1 (high sardine egg density) and Region 2 (low egg density). Region 1 was between CalCOFI line 63.3 and 85.0 (Figure 1) where the egg density in CUFES collections was at least 1 egg per minute. The sizes of Region 1 and the standard DEPM survey area were calculated using the formula for a trapezoid area based on the distance between CalCOFI lines and the distance between CalCOFI stations. Region 1 was 41,878 km^2 (13.6% of the standard DEPM area) and Region 2 was 272,603 km^2. Over the years, although the standard DEPM survey area has varied in size, it has been approximately between CalCOFI line 60 (near San Francisco) and line 95 (near San Diego). In 2011, the spawning biomass estimated in the standard DEPM area was considered to be the spawning biomass for the entire survey area (Figure 1).

A total of 923 CUFES samples were collected from the *Frosti* (513) and *Shimada* (410) cruises over the whole survey area. For the DEPM area (CalCOFI line 60.0 to 95), 823 CUFES samples were taken by the *Shimada* (310) and *Frosti* (513). CUFES sampling intervals ranged from 1 to 121 minutes with a mean of 37.41 minutes and median of 30 minutes depending on egg densities observed onboard. The total number of CalVET tows was 154 for the entire survey area, with 151 in the standard DEPM survey area. A total of 46 CalVET samples caught at least one egg (Table 1). Egg densities from each CalVET sample and from the CUFES samples taken within an hour before and after the CalVET tow were paired and used to derive a conversion factor (*E*) from eggs/min of CUFES sample to CalVET catch (eggs/tow). We used a regression estimator to compute the ratio of mean eggs/min from CUFES to mean eggs/tow from CalVET: $E = \mu_y / \mu_x$ where *y* is eggs/min and *x* is eggs/tow.

For adult samples, the survey plan was to use the *Shimada* and the *Frosti* to conduct 3 – 5 trawls a night either near regular CalCOFI stations or at random sites on the survey line regardless of the presence of sardine eggs in CUFES collections. At night a Nordic 264 rope trawl with 3.0 m^2 foam core doors was towed for 30 minutes at the surface (0 – 11 meters). The trawl was modified for surface trawling with Polyform floats attached to the head rope and trawl wings. The trawl was modified with a marine mammal extruder device placed midsection just forward of the codend. In addition, on the *Frosti*, the first trawl of the night (about a half hour after sunset) was towed without the Polyform floats to depths of 15 to 20 meters to potentially catch fish that might still be moving up toward the surface from daytime depths since dark had not fully descended. For the whole CCE survey, trawling occurred from March 23 to April 25, 2011 and 37 of the 105 trawls conducted at night were positive for Pacific sardines. A single trawl off Astoria, Oregon collected 2 immature sardines. The other 36 trawls with sardines were located in the south below latitude 37.4°N (Figure 1).

Up to 50 sardines were randomly sampled from each positive trawl with more than 75 fish, or all were sampled if fewer than 76 fish were captured (Table 2). After the random subsample, additional mature females were randomly processed, if necessary, from the trawl catch to obtain 25 mature females per trawl for reproductive parameters or to obtain females for use in estimating batch fecundity. Each fish was sexed, standard length (mm) and weight (g) were measured, otoliths were removed for aging, tissue was preserved in 95% ethanol for genetics, and, for females, ovaries were removed and preserved in 10% neutral buffered formalin. Each preserved ovary was blotted and weighed to the nearest milligram in the laboratory. Ovary wet weight was calculated as preserved ovary weight times 0.78 (unpublished data, CDFG 1986). A piece of each ovary was removed and prepared as hematoxylin and eosin (H&E) histological slides. All slides were analyzed for oocyte development, atresia, and postovulatory follicle age to assign female maturity and reproductive state (Macewicz et al. 1996).

Daily egg production (P_0)

Because no eggs or adults were collected north of latitude 37.5°N (CalCOFI line 61.7), the spawning biomass was most likely distributed in the survey area south of San Francisco, the standard DEPM survey area. The estimate of P_0, and thus spawning biomass for the standard DEPM survey area (i.e., the area between CalCOFI line 60.0 and 95) were also used for the entire survey area differed from some of the previous years, e.g. 2006. Appropriate parameter estimates required by the DEPM were obtained for each region.

Similar to the 2001 – 2005 procedure (Lo 2001), we used a net tow as the sampling unit. Sardine eggs from CalVET tows and sardine yolk-sac larvae from both CalVET and Bongo tows in Region 1 were used to compute egg production, primarily based on data from 13 transects (Figure 1). In Region 1, a total of 35 out of 48 CalVET samples contained at least 1 sardine egg; these eggs were examined for their developmental stages (Figure 2 and Table 1). In the total Region 2 (North plus DEPM), 11 out of 107 CalVET tows caught sardine eggs.

Based on aboard-ship counts of sardine eggs in CUFES samples, 333 of the 923 collections were positive for sardine eggs over the entire survey area. For the DEPM area (south of CalCOFI line 60.0), 333 of 823 collections caught sardine eggs. In Region 1, there were 131 positive CUFES collections out of 161 total collections. In the DEPM Region 2, 202 of the total 762 collections were positive. None of the CUFES samples taken north of CalCOFI line 60.0 were positive (Table 1).

To model the embryonic mortality curve, we included yolk-sac larvae (preserved larvae ≤ 5 mm notochord length), assuming that the mortality rate of yolk-sac larvae was the same as that of eggs (Lo 1986). Yolk-sac larval production was computed as the number of yolk-sac larvae/0.05m^2 divided by the duration of the yolk-sac stage (number of larvae/0.05m^2/day). Duration was computed based on the temperature-dependent growth curve (Table 3 of Zweifel and Lasker 1976) for each tow. For yolk-sac larvae caught by the Bongo net, larval abundance was further adjusted for size-specific extrusion from 0.505 mm mesh (Table 7 of Lo 1983) and for the percent of each sample that was sorted. The adjusted yolk-sac larvae/0.05 m^2 was then computed for each tow and termed daily larval production/0.05 m^2.

In the whole survey area, 32 of 154 CalVET and 49 of 132 Bongo samples had at least one yolk-sac larva (Table 1). In Region 1 (Figure 3), 18 of 48 CalVET and 10 of 11 Bongo samples were positive for yolk-sac larvae (all within the DEPM area), and in Region 2, 14 of 106 CalVET and 39 of 121 Bongo samples were positive for yolk-sac larvae. In the DEPM survey area (area south of CalCOFI line 60), 32 out of 151 Calvet and 49 out of 129 Bongo samples had at least one yolk-sac larvae. In Region 1, 18 of 48 CalVET and 10 of 11 Bongo samples were positive for yolk-sac larvae, and in Region 2, 14 of 106 CalVET and 39 of 121 Bongo samples were positive for yolk-sac larvae (Table 1).

Daily egg production for the whole survey area (29.87°N – 47.80°N)

Because no eggs were collected in the area north of CalCOFI line 61.7 (lat 37.5 ^{o}N) (Figure 1), and most stations were south of CalCOFI line 61.7, P_0 (daily egg production/0.05m^2) was computed based on the area south of CalCOFI line 60.0, the standard DEPM survey area.

Daily egg production in Region 1 ($P_{0,1}$) for the standard DEPM survey area (south of CalCOFI line 60.0)

Sardine eggs and yolk-sac larvae and their ages were used to construct an embryonic mortality curve (Lo et al. 1996). Sardine egg density for each developmental stage was computed based on CalVET samples (Figure 2). The distribution of overall density of eggs by egg development stage in 2011, with peak at stage 3, was different from those in recent years when stage 6 or stages 6-9 had the highest density (Lo et al. 2009 and 2010b). The average sea surface temperature for CalVET tows with ≥1 egg in this DEPM survey area was 13.5°C, which is lower than in recent years (Lo et al. 2010b). A temperature-dependent stage-to-age model (Lo et. al. 1996) was used to assign age to each stage. Sardine eggs and estimated ages were used directly in nonlinear regression. Eggs ≤ 3h old and eggs older than 2.5 days were excluded because of possible bias. The average sea surface temperature for all CalVET tows from *Frosti* was 13.5°C, while from the *Shimada* it was 13.9°C for the tows in the standard DEPM survey area.

The sardine embryonic mortality curve was modeled by an exponential decay curve (Lo et al. 1996):

$$P_t = P_{\mathbf{0}} e^{-zt} \qquad [1]$$

where P_t is either eggs/0.05m^2/day from CalVET tows or yolk-sac-larvae/0.05m^2/day from CalVET and Bongo tows, and t is the age (days) of eggs or yolk-sac larvae from each tow. A weighted nonlinear regression was used to estimate two parameters in equation (1) where the weights were 1/SD. The standard deviation (SD) of eggs was 10.25, 3.26, and 2.55, for day-one, day-two and day-three age groups from CalVET samples, respectively, and the SD for yolk-sac larvae was 0.45 and 0.89 from CalVET and Bongo samples, respectively.

A simulation study (Lo 2001) indicated that $P_{0,1}$ computed from a weighted nonlinear regression based on the original data points has a relative bias (RB) of -0.04 of the estimate, where the RB = (mean of 1,000 estimates - true value)/mean of 1,000 estimates. Therefore the bias-corrected estimate of egg production in Region 1 is calculated as $P_{0,1,c} = P_{0,1} * (1 - \text{RB}) = P_{0,1} *(1.04)$, and SE ($P_{0,1,c}$) = SE($P_{0,1}$) * 1.04.

Daily egg production in Region 2 ($P_{0,2}$) for the standard DEPM survey area

Although 104 CalVET samples were taken in Region 2, only 11 tows had ≥ 1 sardine egg, ranging from 1 to 39 eggs per tow (Table 1). Therefore, we estimated daily egg production in Region 2 ($P_{0,2}$) as the product of the bias-corrected egg production in Region 1 ($P_{0,1,c}$) and the ratio (q) of egg density in Region 2 to Region 1 from CUFES samples, assuming the catch ratio of eggs/min from CUFES to eggs/tow from CalVET was the same for the whole survey area:

$$P_{\mathbf{0,2}} = P_{\mathbf{0,1},c}\, q \qquad [2]$$

$$q = \frac{\sum_i \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}} m_i}{\sum_i m_i} \qquad [3]$$

$$\text{var}(q) = \frac{[n/(n-1)]\sum_i m_i^2 (q_i - q)^2}{\left(\sum_i m_i\right)^2}$$

where q is the ratio of eggs/min between the low density and high density areas, m_i was the total CUFES time (minutes) in the i$^{\text{th}}$ transect, $\bar{x}_{j,i}$ is eggs/min of the i$^{\text{th}}$ transect in the j$^{\text{th}}$ Region, and $q_i = \frac{\bar{x}_{2,i}}{\bar{x}_{1,i}}$ is the catch ratio in the i$^{\text{th}}$ transect. The estimates of q were computed from a total of 7 transect lines occupied by both the *Frosti* and the *Shimada* in Region 1. The ratio q was computed from the sub-DEPM area (187,287 km^2), between Calcofi line 63.3 to 86.7 to obtain the initial daily egg production in Region 2 (145,389 km^2), because only two CUFES collections had sardine eggs ranging from 0.01 to 0.12 egg/minutes south of CalCOFI line 86.7. The area north of the sub-area: between CalCOFI line 60.0- 63.3 (6,859 km^2) and the area south of the sub DEPM area (120,335 km^2) were added to region 2 in the sub DEPM area as the total area of the Region 2 (272,603 km^2) in the standard DEPM survey area (314,481 km^2) (Figure 1). $P_{0,2}$ for the standard DEPM area, from CalCOFI lines 60.0 - 95, was prorated from the sub-area.

Daily egg production (P_0) for the standard DEPM survey area

P_0 was computed as the weighted average of $P_{0,1}$ and $P_{0,2}$:

$$P_0 = \frac{P_{0,1,c}A_1 + P_{0,2}A_2}{A_1 + A_2} \tag{4}$$
$$= P_{0,1,c}w_1 + P_{0,2}w_2$$
$$= P_{0,1,c}[w_1 + qw_2]$$

and

$$mse(P_0) = mse(P_{0,1,c})(w_1 + w_2 q)^2 + P_{0,1,c}^2 w_2^2 V(q) - mse(P_{0,1,c})w_2^2 V(q)$$

(Goodman 1960) where $mse\ (P_{0,1,c}) = v(P_{0,1}) + bias^2 = v(P_{0,1}) + (P_{0,1}\ RB)^2$
and $w_i = \frac{A_i}{A_1 + A_2}$, and A_i is the area size for i = 1 or 2 for the DEPM survey area.
The above P_0 was computed for the DEPM area: $P_{0,DEPM} = \sum P_{0,i,\ DEPM}\ W_{i,DEPM}$ where the weights are $W_{i,DEPM} = A_{i,DEPM} / A_{DEPM}$ for i = 1, or 2. $A_{DEPM} = A_{1,DEPM} + A_{2,\ DEPM}$ where $A_{i,DEPM}$ is the area for the ith region in the standard survey area (41,878 km^2). For Region 1, $P_{0,1,DEPM} = P_{0,1}$. For Region 2, $P_{0,2,DEPM} = P_{0,2}$ x $A_{2,\ sub\ DEPM} / A_{2,\ DEPM} = P_{0,I,c}$ x q x (145,389/272,603) where $A_{2,\ sub\text{-}DEPM}$ was the area between CalCOFI line 63.3 and 86.7 and $A_{2,\ DEPM}$ was the area of the DEPM Region 2. CV ($P_{0,DEPM}$)= se ($P_{0,DEPM}$)/ $P_{0,DEPM}$ where se ($P_{0,DEPM}$) = sqrt [(se ($P_{0,1}$) * $W_{1,DEPM}$)^2 + (se ($P_{0,2,DEPM}$) * $W_{2,DEPM}$)^2]. The area of Region 1 for the whole survey area ($A_{1,DEPM}$) was equal to Region 1 in the DEPM survey area (A_1) and CV($P_{0,2,DEPM}$) = CV($P_{0,2}$) . The size of the standard DEPM survey area (area between CalCOFI lines 60.0 and 95.0) is 314,481 km^2 (41,878 km^2 + 272,603 km^2).

Adult parameters

Four adult parameters are needed for estimation of spawning biomass: 1) daily spawning fraction or the number of spawning females per mature female per day (*S*), 2) the average batch fecundity (*F*), 3) the proportion of mature female fish by weight (sex ratio, *R*), and 4) the average weight of mature females (g, W_f). Population values for *S, R, F* and W_f were estimated using the methods of Picquelle and Stauffer (1985). Daily specific fecundity (number of eggs per population weight (g) per day) is $(RSF)/W_f$. The parameters were estimated for the whole and DEPM areas and separately for sardine females caught in each egg-density region. Correlations among all pairs of adult parameters were calculated for computing the variance of the estimate of spawning biomass (Parker 1985). In the past, the predicted batch fecundity for each female fish was calculated as y = a + bx where x is the female weight (without ovary) and y is the predicted value. In reality, most of the batch fecundities we estimated gravimetrically are scattered around the regression line and not on it. Therefore, to account for the deviation of batch fecundity from the regression line, we added an error term to the predicted value as y = a + bx + *e* where error term *e* was a random number generated from a normal distribution with mean zero and a variance of the error terms from the regression analysis. An MS[1] Visual Basic program (Chen et al. 2003) was modified to more accurately describe batch fecundity variance and was used to summarize the trawl adult parameters, calculate adult parameter correlations and covariance, and estimate spawning biomass and its coefficient of variation.

Spawning fraction (S). In total, 244 mature female sardines were analyzed and considered to be a random sample of the population in the area. Histological criteria can be used to identify four different spawning nights: postovulatory follicles aged 44 – 54 hours old indicated spawning two nights before capture (A), postovulatory follicles aged about 20 – 30 hours old indicated spawning the night before capture (B), hydrated oocytes or new (without deterioration) postovulatory follicles indicated spawning the night of capture (C), and early stages of migratory-nucleus oocytes indicated that spawning would have occurred the night after capture (D). The daily spawning fraction can be estimated using the number of females spawning on one night, an average of several nights, or all nights. We used the average of the number of females identified as having spawned the night before capture (B), and those having spawned two nights before capture (A) plus the adjusted number of mature females caught in each trawl (Table 2) to estimate the 2011 population spawning fraction (S_{12}) and variance (Picquelle and Stauffer 1985, Hill et al. 2009).

Batch fecundity (F). Batch fecundity (number of oocytes per spawn) was considered to be the number of migratory-nucleus-stage oocytes or the number of hydrated oocytes in the ovary (Hunter et al., 1985). We used the gravimetric method (Macewicz et al. 1996; Hunter et al. 1985, 1992) to estimate mean batch fecundity for 52 females caught during the April 2011 survey. The relationship of batch fecundity (F_b) to female weight (without ovary, W_{of}), as determined by simple linear regression, was $F_b = -2252 + 347.6W_{of}$,where $r^2 = 0.678$, variance of the slope was 1146.5, and W_{of} ranged from 68 to 180 g (Figure 4); the intercept did not differ from zero ($P = 0.582$). We used the equation $F_b = -2252 + 347.6W_{of} + e$ where the error term, e, was generated from a normal distribution with mean zero and variance of 53,584,146 to estimate batch fecundity for each of the 244 mature Pacific sardine females that were analyzed to estimate spawning frequency.

Female weight (W_f). The observed female weight was adjusted downward for females with hydrated ovaries, because their ovary weights were temporarily inflated. We obtained the adjusted female weight by the linear equation $W_f = -0.59 + 1.07W_{of}$ where W_f is wet weight and W_{of} is ovary-free wet weight based on data from non-hydrated females taken during the April 2011 CCE survey.

Sex ratio (R). The female proportion by weight was determined for each trawl (or each collection). The average weight of males and females (calculated from the first 10 males and 25 females) was multiplied by the number of males or females in the collection of randomly selected fish to calculate total weight by sex in each collection. Thus, the female proportion by weight in each collection (Table 2) was calculated as estimated total female weight divided by

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

estimated total weight in the sample. The estimate of the population's sex ratio by weight was also calculated (Picquelle and Stauffer, 1985).

Spawning biomass (B_s)

The spawning biomass was computed:

$$B_s = \frac{P_0 AC}{RSF / W_f} \qquad [5]$$

where A is the survey area in units of 0.05m^2, S is the fraction of mature females spawning per female per day, F is the batch fecundity (number of eggs per mature female released per spawning), R is the fraction of mature female fish by weight (sex ratio), W_f is the average weight of mature females (g), and C is the conversion factor from grams (g) to metric tons (mt). P_0A is the total daily egg production in the survey area, and the denominator (RSF/W_f) is the daily specific fecundity (number of eggs/population weight (g)/day).

The variance of the spawning biomass estimate $\left(\hat{B}_s\right)$ was computed using Taylor expansion and in terms of the coefficient of variation (CV) for each parameter estimate and covariance for adult parameter estimates (Parker 1985):

$$VAR\left(\hat{B}_s\right) = \hat{B}_s^{\,2}\left[CV\left(\hat{P}_0\right)^2 + CV\left(\hat{W}_f\right)^2 + CV\left(\hat{S}\right)^2 + CV\left(\hat{R}\right)^2 + CV\left(\hat{F}\right)^2 + 2COVS\right] \qquad [6]$$

The last term, involving the covariance term, on the right-hand side is

$$COVS = \sum_i \sum_{i<j} sign \frac{COV\left(x_i, x_j\right)}{x_i x_j}$$

where x's are the adult parameter estimates, and subscripts i and j represent different adult parameters; e.g., $x_i = F$ and $x_j = W_f$. The sign of any two terms is positive if they are both in the numerator of B_S or denominator of B_S (equation 5); otherwise, the sign is negative. The covariance term is

$$COV(x_i, x_j) = \frac{[n/(n-1)]\sum_k m_k (x_{i,k} - x_i) g_k (x_{j,k} - x_j)}{\left(\sum_k m_k\right)\left(\sum_k g_k\right)}$$

where k refers to k^{th} tow, and $k = 1,\ldots,n$. The terms of m_k and g_k are sample sizes and $x_{i,k}$ and $x_{j,k}$ are sample means from the k^{th} tow for x_i and x_j respectively.

The survey area was post-stratified into two regions based on the presence of sardine eggs: Region 1 (high-density area) and Region 2 (low-density area). Thus, equation (5) can be applied to the whole survey area and/or to each of the two regions depending on the availability of data. For the female spawning biomass (fs.biomass), one of the inputs to the stock assessment, the sex ratio (R), was excluded from equations (5) and (6). The estimate of female spawning biomass was the sum of the estimate from each of the two regions, which is referred to as the stratified procedure. The traditional method is to obtain a weighted mean for P_0 (equation 4), while each of the adult parameter was an unstratified estimate.

RESULTS

Daily egg production (P_0) for the standard DEPM survey area and the whole survey area

In Region 1, the initial daily egg production ($P_{0,1}$) from the mortality curve was 5.366/0.05 m^2/day (CV = 0.24; equation 1 and Figure 5). The bias-corrected egg production, ($P_{0,1,c}$) was 5.57 (CV = 0.24) (Table 3) for an area of 41,878 km^2 (south of CalCOFI line 61.7). The ratio (q) of egg density between Region 2 and Region 1 from CUFES samples was 0.164 (CV = 0.23) (equation 3). The egg production ($P_{0,2}$) in Region 2 of the sub-DEPM surey area, was 0.914 /0.05 m^2/day (CV = 0.5) for an area of 187,287 km^2 (54,722 nm^2) and 0.487 eggs/0.05m2 for the Region 2 area (272,603 km^2) in the standard DEPM survey area. Egg mortality (0.51 (CV = 0.14)) was higher than in many years (Table 4). The P_0 for the standard DEPM survey area was 1.16/0.05 m^2 (CV = 0.26) (equation 4) for 314,481 km^2 (91,866 nm^2) (Table 3).

Catch ratio between CUFES and CalVET (E)

Although this ratio is no longer needed in the current estimation procedure, we computed it for comparison purposes. The catch ratio of eggs/min to eggs/tow (eggs/min = E * eggs/0.05 m^2) was computed from 46 pairs of CalVET tows and CUFES collections from the *Frosti* and *Shimada* cruises (Figure 6). The eggs/min corresponding to each positive CalVET tow was the mean of all CUFES collections taken from one hour before to one hour after each positive CalVET tow. The catch ratio was 0.0589 (CV = 0.21) in comparison to the 2010 estimate of 0.077(CV = 0.14). A ratio of 0.058 means that one egg/tow from a CalVET tow was equivalent to approximately 0.058 egg/min from a CUFES sample, or one egg/minute from the CUFES was equivalent to 17.24 eggs/tow from the CalVET sample.

The ratio of egg densities of two regions from pump samples (q)

The q value (ratio of eggs/min in Region 1 to eggs/min in Region 2) serves as the calibration factor to estimate $P_{0,2}$ in Region 2 (equation 2). It is needed because low abundance of eggs observed in Region 2 prevents us from using the egg mortality curve to directly estimate $P_{0,2}$. For the 2011 survey, q was obtained from 7 transect lines between CalCOFI lines 81.7 and 70.0. The estimate was 0.164 (CV = 0.23).

Adult parameters

Over the whole survey area trawled (31.3° – 46.74°N) during the April 2011 CCE survey, only one tow caught sardines north of CalCOFI line 60 at 46.04°N. Since both of these sardines were caught in a single tow and were immature (sizes were 146 and 147 mm SL), and no sardine eggs were found, a coastwide spawning biomass was not estimated. In the standard DEPM survey area off California (from CalCOFI lines 95 to 60), Pacific sardines were found in 36 tows: mature female sardines were found in 30 tows, 4 tows contained immature females, and 2 tows had only a single male (Table 2). Standard length (SL) of the randomly obtained sardines in each trawl ranged from 153 to 248 mm for 292 males and from 155 to 268 mm for 374 females. The smallest mature female was 173 mm SL. Since 104 immature female sardines (size range 146 to 196 mm SL) were captured during the 2011 survey, the length at which 50% of females are mature (ML_{50}) was calculated as 186.47 mm (Figure 7) using logistic regression (Macewicz et al. 1996, Lo et al. 2005).

The DEPM survey area off California in 2011 was 314,481 km^2. Estimates of reproductive parameters of 244 mature female sardines (up to 25 mature females analyzed per trawl) for the individual trawls are given in Table 2. The mature female Pacific sardine reproductive parameters in the standard DEPM survey area, estimated from 30 positive trawls (Table 2) and 244 mature females, were: *F*, mean batch fecundity, 38,369 eggs/batch (CV = 0.07); *S*, fraction spawning per day, 0.1078 females spawning per day (CV = 0.18); W_f, mean female fish weight, 127.6 g (CV = 0.05); and *R*, sex ratio of females by weight, 0.587 (CV = 0.06) (Table 5). The average interval between spawning bouts (spawning frequency) was about 9 days (inverse of spawning fraction or 1/0.1078), and the daily specific fecundity was 19.04 eggs/population weight (g)/day (Table 5). The correlation matrix for the adult parameter estimates for the DEPM Region 1 and Region 2, and the whole DEPM area is shown in Table 5. We also provid estimates of each adult parameter in each region (Table 5), primarily because they are used to compute female spawning biomass, which is the input of fishery-independent spawning biomass time series to the stock assessment (Hill et al. 2011).

Spawning biomass (B_s)

The final estimate of spawning biomass of Pacific sardines in 2011 using the traditional method (equation 1 and 4, Table 3 and 4) was 383,286 mt (CV = 0.32) or 421,615 short tons (st) (= mt x 1.1) for the standard DEPM survey area of 314,480.98 km^2 (91,886 nm^2) off California. The yearly point estimates of spawning biomass of Pacific sardine off California in 1994 – 2011 were, respectively, 127,102; 79,997; 83,176; 409,579; 313,986; 282,248; 1,063,837; 790,925; 206,333; 485,121; 281,639; 621,657; 837,501; 392,492, 117,426, 185,084, 108,280 and 383,286 mt (Table 4). Based on the stratified procedure, the estimate of the 2011 spawning biomass was 373,348 mt (CV = 0.28) (Table 3 and 6).

The estimate of the female spawning biomass for the DEPM survey area was 219,386 mt (CV = 0.28) and 225,155 mt (CV = 0.32) based on the stratified procedure and the traditional method respectively. The former with estimates of previous years was used as one time series input to the Pacific sardine stock assessment (Table 6).

DISCUSSION

Sardine eggs

Sardine eggs in April 2011 were concentrated in the area between CalCOFI lines 63.3 and 83.3 up to offshore CalCOFI station 100.0 in an area of close to 42,000 km^2 (Figure 1),. This region is larger than the area in 2010, when eggs were distributed only between CalCOFI lines 63.3 and 73.3, and further north than in 2009, when eggs were distributed between CalCOFI lines 81.7 and 95.0 (Lo et al. 2010b and 2009). The change in distribution of eggs in 2010 and 2011 from previous years could be due to low water temperature or other environmental conditions. As in 2010, the area north of CalCOFI line 60.0 had zero eggs. The daily egg production rate of 5.57/0.05m^2 in the high-density area was much higher than in 2007-2010 (Table 6). However, the high-density area was only 13% of the standard DEPM survey area, much lower than in most previous years (e.g., 27% in 2009). The high overall P_0 of 1.16/0.05 m^2 for the standard DEPM survey area was similar to that in 2004. The spawning area has been in the southern part of California waters since 2006, even though few eggs have been observed in Mexican surveys, i.e. IMECOCAL. In the past, eggs were concentrated north of Point Conception in 1999, 2004 and 2005. The relatively small size of Region 1 in 2011, and its northern location (between CalCOFI line 63.3 and 83.3) which was somewhat more southern compared to 2010 (Figure 8), could be due to a minor La Niña year and/or other environmental conditions. Moreover, in 2006 CCE survey, eggs were observed around latitudes 40 – 43^{o}N, which was not true for the 2008 and the 2011 CCE surveys.

The adaptive allocation sampling procedure was used aboard the *Frosti* and the *Shimada*. (including April CalCOFI survey). A total of 151 CalVET tows was taken in the standard DEPM survey area. This was higher than in many previous years (129 in 2010, 136 in 2009, 84 in 2007, 123 in 2006, 74 in 2005, and 124 tows in 2004), but smaller than in other recent years (217 in 2002, 192 in 2003 and the same in 2008). Unlike in the previous years, however, adaptive sampling was used during the April CalCOFI survey in 2011. Due to the low egg densities south of CalCOFI line 83.3, no extra CalVET tows were taken. We still highly recommend that adaptive allocation sampling be applied during the spring (March – April) routine CalCOFI survey in the future to enhance the quality of the estimate of the spawning biomass.

Embryonic mortality curve

The estimates of the daily egg production at age 0 (P_0/0.05 m^2 = 5.366 with CV = 0.24) and the daily embryonic mortality (0.51, CV = 0.14) from the mortality curve in Region 1 were much higher than in recent years from 2007-2010, but similar to that in 2006. The high value of P_0 was partially caused by the distribution of egg developmental stages (Figure 2). In many past years, the peak egg developmental stage was stage 6. In 2011, however, the peak egg development stage was stage 3. Another extreme case was in 2010, when the peak densities spread from stage 6 to 9 (Lo et al. 2010b). The latter phenomenon is not understood and needs thorough investigation. The overall P_0 in the DEPM (1.16 eggs/0.05m^2) was higher than in previous years (Table 3 and 4), despite the relatively small size of the high density area (Figure

1). The spatial distribution of yolk-sac larvae was broader than in 2010, in particular on the southern CalCOFI lines (Figure 3). This could be caused by the relative late dates of sampling aboard *Shimada* at the end of April. Those yolk-sac larvae in Region 2 were not used in the computation of spawning biomass.

Catch ratio between CUFES and CalVET (E)

The 2011 catch ratio between CUFES and CalVET (0.058) computed from data obtained from the *Frosti* and *Shimada* appeared to be the lowest among all years: 2010 (0.077), 2009 (0.15), 2008 (0.14), 2007 (0.15), 2006 (0.32(CV = 0.12)), 2005 (0.18 (CV = 0.28)), 2004 (0.22 (CV = 0.09)), 2003 (0.39 (CV = 0.11)), 2002 (0.24 (CV = 0.06)), 2001 (0.145 (CV = 0.026)), 2000 (0.27), 1999 (0.34), and 1998 (0.32). This low catch ratio in 2011 indicated that relatively fewer eggs were in the upper 3 meters of the water column, possibly due to weakly mixed ocean water. In particular, the current catch ratio was much lower than the 1996 estimate of 0.73. This could be because the 1996 CalVET samples were taken only in the southern area near San Diego (routine CalCOFI survey area) while after 1997 CalVET samples were taken in a larger area extending far north of San Diego (Lo et al. 2005). It would be informative to examine the relationship between the catch ratio and the degree of water mixing over the years (Lo et al. 2001).

The ratio of egg densities of two regions from pump samples (q)

The *q* value (ratio of eggs/min in Region 1 to eggs/min in Region 2) (equation 2) was 0.164 (CV=0.23), slightly higher than 2010's estimate: 0.128 (CV = 0.37) for the standard DEPM sampling area. This value, with the exception of that for 2007 (0.48), was higher than those of previous years. The q values have ranged from 0.036 to 0.085 in 2001-2006 with an increasing trend. If this trend continues, it may mean that the spatial distribution of sardine eggs is becoming less aggregated, as the difference of densities of eggs between these two regions would be less.

Adult parameters

The April 2011 CCE survey again covered a large area off the west coast of the U.S. from Cape Flattery, WA to San Diego, CA. Previous trawling was conducted in the spring off the whole west coast during 2006, 2008, and 2010 (Lo et al. 2007a, 2008, 2010b). We examined the range of sea temperatures at 3m depth, recorded during trawl operations, in three subareas off the coast: Washington and Oregon, northern California, and the standard DEPM area (Table 7). Although only five trawls were conducted off Washington-Oregon (9.4 – 9.5^{o}C), two immature sardines (mean of 146.5mm and 31g) were caught off Astoria, Oregon. The last time we caught sardines in a survey off Washington and Oregon was in March of 2004 and 2005 when a majority of the sardines were small, immature, and found in cooler waters (average about 10.2°C) than mature female sardines (Lo et al. 2010a). No trawls were conducted in northern California water, due to weather and those in time constraints. Temperatures recorded during CUFES sampling (9.9 – 11.9^{o}C) were similar to previous surveys indicating that sardines would possibly have been caught off northern CA if trawling had occurred. In the standard DEPM area during 2011 (9.9 – 16.3^{o}C) sardine adults and eggs were collected as in past surveys. Although during 2006-2010, the size of sardines caught increased, and both the size of Region 1 (high sardine egg density) and P_0 (daily egg production) decreased, in 2011. Sardines were smaller and both P_0 and the area of Region 1 were larger, indicating possible improvement of recruitment.

During the April 2011 survey in the standard DEPM survey area, we were again able to collect trawl samples (Table 2) in areas of high (Region 1) and low (Region 2) sardine egg densities to yield a better estimate of Pacific sardine spawning biomass for the whole population in the large oceanic area from San Diego to San Francisco. We found that the average mature female weight (W_f) was similar in both regions (128.4 grams (SE = 4.16) in Region 1 and 126.9 grams (SE = 11.27) in Region 2, Table 5) while the fraction of females spawning per day, S_{12}, (based on the average of females that spawned the night before capture and 2 night before capture or "average of day 1+day 2") was higher in Region 1 (0.136 females/day (CV = 0.18)) than Region 2 (0.084 females/day (CV = 0.35)). This regional difference in the fraction of females spawning (high in 1 and lower in 2) was similar to that in past DEPM surveys in 2005, 2006 (Lo and Macewicz 2006, Lo et al. 2007a), 2007 (when one unusual trawl is removed, Lo et al. 2007b), 2008, 2009, and 2010 (Lo et al. 2008, 2009, 2010b). Although there were more trawls conducted in Region 2 (78) than in Region 1 (22), about the same number of trawls contained mature females (Table 5), and when trawls with only males or immatures are included there were slightly more positive trawls in Region 2 (21) than in Region 1 (15). Most trawls taken in Region 2 failed to catch any sardines. In the future, we may reduce number of trawls in Region 2 when the egg density is zero or consistently less than 1 egg/min. However, because more females were spawning per day in Region 1 than Region 2, it is necessary to continue to trawl in both regions to ensure an unbiased estimate of spawning biomass for the whole population.

In 2011 the CV (0.18) of the spawning fraction estimate in the DEPM area was higher than in 2009 (CV = 0.15) but lower than in 2010 (CV = 0.22) and in earlier years (CVs of 0.33 in 2007 and 0.31 in 2005 and 2008) (Lo et al. 2006, 2007b, 2008, 2009, and 2010b). The high CVs in previous years were most likely due to the low number of sardine positive trawls (12 – 14) and high variability of spawning (Table 8). In 2011, as in 2010 and 2009, a factor in improvement of the CV was the change in the calculation of daily spawning fraction. In the past (1994, 1997, 2004, 2005, 2007, and 2008), calculation of the original daily spawning fraction (S_1) was based on the number of females that spawned the night before capture (night B, "day 1") and followed the procedure for northern anchovy (Picquelle and Hewitt, 1983) to replace the number of females spawning the night of capture (night C, "day 0") with the number of night B spawning females to adjust the number of total mature females. By contrast, since 2009 we calculated the daily spawning fraction (S_{12}) using the mean number of night B and night A (two nights before capture, "day 2") spawning females for each trawl and replaced the night C females by this mean to adjust the number of total mature females. Another factor accounting for the lower CV of the 2011 and 2009 spawning fraction estimate was an increase in the number of trawls with sardines (30 in 2011 and 29 in 2009), while 2010 had fewer sardine positive trawls (17) and hence a slightly higher CV (0.22) (Table 8). Therefore for continued improvement of spawning fraction precision, we recommend using S_{12} to calculate daily spawning fraction and that at least 17 trawl samples need to be obtained or the number of trawls sampled be increased, in both high and low egg density areas, for future biomass surveys.

We estimated that 50% of the female sardines were mature (ML_{50}) at 186.47 mm during April 2011 (Figure 7). The April 2011 estimate of ML_{50} is between the 2004 value (193 mm) and the 1997 value (171 mm) and higher than the estimates from 2007(153 mm), 2005 (152 mm) and 1994 (159 mm) (Lo et al. 2005 and 2007b, Lo and Macewicz 2006). The variation in ML_{50} could be real due to change in maturity or it may be the result of sample bias from one or more of the following: a) sardines were from the high egg density area only, b) all or a majority of the sardines were from offshore, c) all or a majority of the sardines were from inshore or near islands, d) migration of sardine subpopulation occured, and e) age and length relationship changed. We recommend continued evaluation of maturity to eliminate any biases.

We examined the relative frequency of length of sardines taken in 2011 and compared them to those taken during a similar period in the standard DEPM area in previous years (Figure 8 and 9). The mean size of sardines (male and females) was slightly smaller than in the recent three years (2008-2010), slightly larger than in 2005-2007, and much smaller than in 2004 (Figure 9). The length distribution of sardine caught during 2011 shows two size modes: one peaking at about 185 mm and the other at about 230 mm with a severe dip in the 210 mm length class (Figure 8). The smaller size mode was almost absent in 2010 and low in quantity in 2008 and 2009 surveys while the larger lengths are consistent with increasing size of an aging fish population during 2008-2010. Sixty two percent of the females caught between 155mm and 194 mm standard length were immature in 2011. We believe that the most likely explanation for the smaller fish is good recruitment of the 2010 year class. It could possibly also be due to 1) conducting trawls and capturing sardines inshore (6 trawls with sardine in 2011, 0 during 2008-2010) where sardines are known to be small relative to offshore (Lo et al. 2007a), or 2) movement of smaller sizes slightly farther offshore, since 43% of offshore sardine were less than 195 mm standard length. We recommend that to improve the whole population adult parameter analyses more trawls should continued to be added in the inshore areas to obtain spawning and maturity information on smaller fish to avoid possible bias against smaller fish.

Spawning biomass

In the DEPM survey area, the 2011 estimate of spawning biomass using the traditional method was 383,286 mt, based on the egg production of 1.16 eggs/0.05m$^{2/}$day, and the daily specific fecundity of 19.04 eggs/g/day. This production was mostly in the area between CalCOFI line 70.0 and 83.3 (35.5 °N and 34.16 °N). The spawning biomass was considerably higher than for most previous years (Table 4). The high spawning biomass is primarily due to the high egg production in the high-density area (Table 3) and an average adult reproductive output (Table 3). Note that the egg production rate of 5.57 eggs/0.05m^2 in the high-density area was higher than in 2010: 1.70 eggs/0.05m2, and 2009: 1.69 eggs/.05m^2 (Lo et al. 2009). The overall daily egg production, 1.16 eggs/0.05m2, is much higher than in most recent years: 0.36 eggs/0.05m^2/day in 2010, 0.59 in 2009, 0.43 in 2008, 0.864 in 2007, and lower than 1.936 in 2006, and 1.916 eggs/0.05m^2 in 2005. The area of Region 1 of 41,000 km^2 was larger than 27,462 km^2 in 2010 and smaller than in other years. The adult daily reproductive output (daily specific fecundity) was similar to that in the previous year. The higher values in early years were due to the fact that trawl samples were taken in the high-density area only. Since 2005, trawl samples have been taken in both Region 1 and Region 2. The high daily egg production rate and the daily specific fecundity (19.04) are similar to the 2010 estimate (18.07), indicating that the spawning biomass is increasing. The difference between the estimates of spawning biomasses between 2010 and 2011 was statistically significant ($t = 2.6$, $p<0.05$). The significant difference of spawning biomass indicated that the spawning biomass of Pacific sardine did not decline from 2010 to 2011. For the stock assessment, we provided the estimates of female spawning biomass for years where adequate adult samples were available (Table 6).

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Table 1. Number of positive tows of sardine eggs from CalVET, yolk-sac larvae from CalVET and Bongo, eggs from CUFES and positive sardine trawls[a] in Region 1 (eggs/min ≥ 1), Region 2 (eggs/min < 1) for *Frosti* , and *Shimada* cruises of 2011 April CCE survey. Both *Shimada* and *Frosti* occupied part of the standard DEPM survey area: *Shimada* occupied the area from from Cape Flattery, Washington to CalCOFI line 93.3, with most stations between CalCOFI lines 93.3 to 63.3. *Frosti* occupied the area from San Francisco to San Diego (CalCOFI line 61.7 to 95.0). The area north of CalCOFI line 60.0 is referred to as 'North' and the standard DEPM survey area is CalCOFI lines 95.0 – 60.0. (note: I did change 61.7 to 60.0 for 2011)

		Region 1			Region 2			Grand Total		
		Total	North	DEPM	Total	North	DEPM	Total	North	DEPM
CalVET Eggs	Positive	35	0	35	11	0	11	46	0	46
	Total	48	0	48	107	3	104	154	3	151
CalVET Yolk-sac	Positive	18	0	18	14	0	14	32	0	32
	Total	48	0	48	107	3	104	154	3	151
Bongo Yolk-sac	Positive	10	0	10	39	0	39	49	0	49
	Total	11	0	11	121	3	118	132	3	129
CUFES Eggs	Positive	131	0	131	202	0	202	333	0	333
	Total	161	0	161	762	100	662	923	100	823
Trawls	Positive	15	--	15	22	1	21	37	1	36
	Total	22	--	22	83	5	78	105	5	100

[a] All sardines were captured at night.

Table 2. Sardine egg density region, individual trawl information, sex ratio[a], and parameters for mature female sardine, *Sardinops sagax*, used in the estimation of the April 2011 west coast spawning biomass. Collection 2740 is north of CalCOFI line 60 and the other 36 trawls are in the standard DEPM sampling area off California.

COLLECTION INFORMATION									MATURE FEMALES							
				Location										Number spawning		
Region 1=high 2=low	No.	Month-Day	Time	Latitude °N	Longitude °W	Surface Temp. °C	No. of fish	Sex Ratio	No. analyzed	Body weight (g) Ave.	Weight without ovary (g) Ave.	Batch Fecundity Ave.	Adj. No.[b]	Night of capture	Night before capture	2 Nights before capture
2	2740	3-24	19:39	46.041	124.320	09.4	2	0.484	0[c]	0.00	0.00	0	0.0	0	0	0
2	2656	4-02	00:46	37.398	122.800	12.6	1	1.000	0[c]	0.00	0.00	0	0.0	0	0	0
2	2743	3-27	19:41	37.233	122.786	12.1	5	0.821	0[c]	0.00	0.00	0	0.0	0	0	0
2	2744	3-27	23:07	37.168	122.933	11.7	26	0.722	1	91.00	83.34	30431	1.0	0	0	0
2	2745	3-28	01:52	37.086	122.801	12.2	8	0.597	1	78.00	73.87	18197	1.0	0	0	0
2	2658	4-03	21:33	36.815	122.244	12.6	4	0.571	0	0.00	0.00	0	0.0	0	0	0
2	2746	3-28	19:33	36.575	124.239	13.0	5	0.878	3	131.50	120.76	35301	3.0	0	0	0
2	2747	3-28	21:43	36.506	124.413	12.9	50	0.702	25	136.82	126.33	40763	24.5	1	0	1
2	2748	3-29	01:15	36.285	124.412	12.7	50	0.516	25	163.76	150.57	50777	23.0	3	1	1
2	2752	4-04	23:59	35.813	124.200	12.7	69	0.627	6	139.17	131.97	38622	6.0	0	0	0
2	2679	4-14	19:08	35.520	123.127	12.8	5	0.637	2	161.44	153.06	41578	1.0	1	0	0
2	2695	4-17	22:36	35.447	121.583	11.6	4	0.728	0[c]	0.00	0.00	0	0.0	0	0	0
2	2680	4-14	21:10	35.428	123.303	12.9	6	0.701	4	139.20	129.76	37063	3.0	1	0	0
1	2754	4-05	22:27	35.371	123.515	12.9	1[d]	0.000	0	0.00	0.00	0	0.0	0	0	0
2	2689	4-15	01:22	35.333	123.048	13.0	6	0.522	3	140.17	131.75	47061	3.0	0	0	0
1	2688	4-14	23:03	35.250	123.238	12.9	1	1.000	1	150.00	142.71	36424	1.5	0	0	1
1	2693	4-16	22:46	34.700	123.211	13.4	13	0.717	8	118.94	112.12	37308	10.0	0	0	4
1	2786	4-25	21:40	34.593	121.841	13.5	21	0.254	5	83.07	78.10	21996	2.0	3	0	0
2	2662	4-08	19:20	34.572	122.746	13.1	2	1.000	2	143.00	132.38	39833	2.0	0	0	0
1	2785	4-25	19:30	34.505	122.027	13.6	2	0.574	1	109.00	101.02	29675	1.0	0	0	0
1	2670	4-10	19:47	34.492	121.293	13.3	83	0.705	25	135.81	127.00	40704	14.5	12	2	1
2	2663	4-08	21:21	34.487	122.891	13.2	36	0.474	14	88.10	81.70	24603	13.5	1	0	1
1	2672	4-11	01:35	34.420	121.432	13.3	4	0.800	3	108.17	102.49	29675	4.5	0	1	2
1	2665	4-09	01:22	34.394	122.653	13.3	50	0.527	25	139.76	130.50	40402	27.0	1	1	5
1	2671	4-10	21:52	34.364	121.145	13.5	7	0.427	3	112.00	105.59	31492	2.0	1	0	0
1	2664	4-08	23:18	34.343	122.812	13.4	40	0.659	23	121.19	112.65	37323	23.5	1	3	0
1	2696	4-18	19:52	34.342	122.343	13.4	27	0.194	5	136.03	128.80	47040	1.5	4	0	1
1	2699	4-19	01:55	34.339	122.215	13.5	2	1.000	2	154.75	147.09	51371	3.0	0	0	2
2	2691	4-16	00:58	34.242	124.213	12.5	50	0.516	18	78.64	75.13	24217	20.0	2	2	6
1	2698	4-18	23:50	34.208	122.236	13.5	7	0.778	5	125.20	118.33	41500	4.5	1	0	1
1	2697	4-18	21:45	34.183	122.381	13.5	8	0.758	6	134.42	127.41	40662	7.0	0	1	1
2	2692	4-16	03:43	34.167	124.369	12.9	52	0.512	16	125.88	119.20	38672	15.0	3	1	3
2	2667	4-09	21:07	33.748	122.840	13.3	4	0.388	1	128.01	120.19	43448	0.0	1	0	0
2	2668	4-09	23:10	33.616	122.754	13.4	1	1.000	1	136.00	131.07	37564	0.0	1	0	0
1	2704	4-20	21:37	33.545	121.576	13.6	3	1.000	3	125.33	120.36	43017	4.5	0	3	0
2	2669	4-10	01:08	33.512	122.870	13.5	11	0.704	7	135.14	130.79	41775	9.5	0	4	1
2	2716	4-24	22:41	32.375	118.908	14.7	1[d]	0.000	0	0.00	0.00	0	0.0	0	0	0
									244				232.0	37	19	31

[a] Sex ratio, proportion of females by weight, based on average weights from subsamples and number of fish sampled in each trawl(Picquelle and Stauffer 1985).

[b] Mature adjusted by the average number of females spawning the night before capture and females spawning 2 nights before capture

[c] Any females caught were immature

[d] Only males captured

Table 3. Egg production (P_0) of the Pacific sardine in 2011 based on egg data from CalVET and yolk-sac larval data from CalVET and Bongo in Region 1 (eggs/min ≥ 1) and Region 2 (eggs/min < 1) from *Frosti* (April 1- 27), and *Shimada* (March 23-April 27) cruises, adult parameters from positive trawls (April 3 – 25), and 2011 spawning biomass estimates.

Parameter	**Region 1**	**Region 2**		**DEPM Area**
		North	DEPM	
CUFES samples	161	100	662	**823**
CalVET samples	47	3	104	**151**
P_0 / 0.05m^2	5.57 [a]	0	0.49	**1.16**
CV	0.24	--	0.33	**0.26**
Area (km^2)	41,878	—	272,603	**314,481**
% Whole coast	—	—	—	**—**
% DEPM area	13	--	87	**100**
Year of adult samples	2011	2011	2011	**2011**
Female fish wt (W_f)	128.36	30.5 [b]	126.92	**127.59**
Batch fecundity (F)	38805	--	37980	**38369**
Spawning fraction (S)	0.136	--	0.084	**0.1078**
Sex ratio (R)	0.589	--	0.586	**0.587**
(RSF)/W_f	24.26	--	14.67	**19.04**
Spawning biomass (mt) Traditional method [c]		--		**383,286**
CV				**0.32**
Spawning biomass (mt) Stratified procedure [d]	192,332	--	181,016	**373,348**
CV	0.31		0.48	**0.28**
Daily mortality (Z)	0.51			
CV	0.14			
eggs/min	1.66		0.23	**0.45**
CV	0.21		0.28	**0.36**
q = eggs/min in Reg.2 / eggs/min in Reg.1				**0.164**
CV				**0.37**
E = (eggs/min)/(eggs/tow)				**0.058**
CV				**0.24**
Bongo samples	11	3	118	**129**
Area in nm^2	12,236	--	79,650	**91,886**
Spawning biomass (short ton) (need to do)	211,565	--	199,118	**410,683**

[a] 5.57 was corrected for bias of P_0.

[b] single immature female and no eggs collected in North, no biomass estimated for this area

[c] biomass was computed from estimates of parameters in each column, e.g., DEPM area is an average of adult parameters from Region 1 and DEPM Region 2.

[d] biomass was computed by the stratified procedure, i.e., total spawning biomass = the sum of the estimates of spawning biomass in Region 1 and Region 2: 373,348 = 192,332 + 181,016.

Table 4. Estimates of daily egg production (P_0)[a] for the DEPM survey area, daily instantaneous mortality rates (Z) from high-density area (Region 1), daily specific fecundity (RSF/W), spawning biomass of Pacific sardines using the traditional method and average sea surface temperature for the years 1994 to 2011.

Year	P_0 (CV)	Z (CV)	Area (km^2) (Region 1)	$\frac{RSF^h}{W}$	Spawning biomass (mt) (CV)[b]	Mean Temp. for positive egg or yolk-sac samples	Mean temperature all CalVETs
1994	0.193 (0.210)	0.120 (0.91)	380,175 (174,880)	11.38	127,102 (0.32)	14.3	14.7
1995	0.830 (05)	0.400 (0.4)	113,188.9 (113188.9)	23.55[c]	79,997 (0.6)	15.5	14.7
1996	0.415 (0.42)	0.105 (4.15)	235,960 (112,322)	23.55	83,176 (0.48)	14.5	15.0
1997	2.770 (0.21)	0.350 (0.14)	174,096 (66,841)	23.55[d]	409,579 (0.31)	13.7	13.9
1998	2.279 (0.34)	0.255 (0.37)	162,253 (162,253)	23.55	313,986 (0.41)	14.38	14.6
1999	1.092 (0.35)	0.100 (0.6)	304,191 (130,890)	23.55	282,248 (0.42)	12.5	12.6
2000	4.235 (0.4)	0.420 (0.73)	295,759 (57,525)	23.55	1,063,837 (0.67)	14.1	14.4
2001	2.898 (0.39)	0.370 (0.21)	321,386 (70,148)	23.55	790,925 (0.45)	13.3	13.2
2002	0.728 (0.17)	0.400 (0.15)	325,082 (88,403)	22.94	206,333 (0.35)	13.6	13.6
2003	1.520 (0.18)	0.480 (0.08)	365,906 (82,578)	22.94	485,121 (0.36)	13.7	13.8
2004	0.960 (0.24)	0.250 (0.04)	320,620 (68,234)	21.86[e]	281,639 (0.3)	13.4	13.7
2005	1.916 (0.417)	0.579 (0.20)	253,620 (46,203)	15.67	621,657 (0.54)	14.21	14.1
2006	1.936 (0.256)	0.31 (0.25)	336,774 (98,034)	15.57[f]	837,501[f] (0.46)	14.95	14.5
2007	0.864 (0.256)	0.133 (0.36)	356,159 (142,403)	15.68	392,492 (0.45)	13.7	13.6
2008[g]	0.43 (0.21)	0.13 (0.29)	297,949 (53,514)	21.82	117,426 (0.43)	13.3	13.1
2009[h]	0.59 (0.22)	0.25 (0.19)	274895 (74,966)	17.53	185,084 (0.28)	13.6	13.5
2010[i]	0.36 (0.40)	0.33 (0.23)	271,773 (27,462)	18.07	108,280 (0.46)	13.7	13.9
2011	1.16 (0.26)	0.51 (0.14)	314,481 (41,878)	19.04	383,286 (0.32)	13.5	13.6

a weighted non-linear regression on original data and bias correction of 1.04, except in 1994 and 1997 when grouped data and a correction factor of 1.14 was used (appendix Lo 2001).

b $CV(B_s) = (CV^2(P_0) + allotherCOV^2)^{1/2} = (CV^2(P_0)+0.054)^{1/2}$. For years 1995 – 2001 $allotherCOV^2$ was from 1994 data (Lo et al. 1996). For year 2003, allotherCOV was from 2002 data (Lo and Macewicz 2002)

c 23.55 was from computation for 1994 based on S = 0.149 (the average spawning fraction (day 0 + day 1) of active females from 1986 – 1994; Macewicz et al. 1996).

d is 25.94 when calculated from parameters in 1997 (table 9) and estimated spawning biomass is 371,725 mt with CV = 0.36

e uses R = 0.5 (Lo and Macewicz 2004); if use actual R = 0.618, then value is 27.0 and biomass is estimated at 227,746 mt

f value for standard DEPM sampling area off California when calculated using S = 0.126, the average of females spawning the night before capture ("day 1") from 1997, 2004, 2005, and 2007. When 2006 survey S of 0.0698 was previously used (Lo et al. 2007a), the 2006 DEPM spawning biomass was estimated as 1,512,882 mt (CV 0.46) and the 2006 coast-wide spawning biomass was estimated as 1,682,260 mt

g standard DEPM sampling area off California from San Diego to CalCOFI line 66.7 whole 2008 survey area off west coast of North America from about 31°N to 48.47°N latitude, spawning biomass was estimated as 135,301 mt(CV=0.43)

h RSF/W from 2009 is based on S_{12},:average of day1 and day2 females.

i The whole survey area was 477,092 km^2 from San Diego, CA to Cape Flattery,Wa. .Very few sardine eggs were observed north of the DEPM survey area (CalCOFI line 60.0 is the northern boundary of the DEPM area)

Table 5. Estimated 2011 adult parameters and correlations for each region[a] in the DEPM area outputted from the EPM program (Appendix II Chen et al. 2003).

Region 1 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	128.3571636	17.3317798261
Gonad Fee Weight	120.342368696	15.0403107045
Batch fecundity	38805.1157582	3809719.74811
Spawners, Day 0	0.2	0.00782387669
Spawners ave (day1+day2)	0.13615015493	0.00059430486
Sex Ratio	0.58929453354	0.00428845086
Daily specific fecundity	24.2560134095	
Number of Sets	14	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.87548224	0.01666435	0.13641787
Batch Fecundity (F)			0.1349069	0.10537435
Fraction Spawning (S)				-0.1250504
Sex Ratio (R)				

Region 2 DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	126.916043473	127.105383264
Gonad Fee Weight	118.520213178	101.432781818
Batch fecundity	37980.8817397	17112443.7393
Spawners, Day 0	0.10852713178	0.00055716306
Spawners ave (day1+day2)	0.08366522311	0.00088167375
Sex Ratio	0.58584137154	0.00096508963
Daily specific fecundity	14.6680887637	
Number of Sets	16	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.99116278	-0.569925	0.07617438
Batch Fecundity (F)			-0.496786	0.00035832
Fraction Spawning (S)				-0.2911582
Sex Ratio (R)				

DEPM area

Statistic Results:

	Average	Variance
Whole Body Weight	127.595259926	38.1929626883
Gonad Fee Weight	119.379015984	30.7762408932
Batch fecundity	38369.3526910	7082578.4693
Spawners, Day 0	0.15163934426	0.00200223903
Spawners ave (day1+day2)	0.10775852155	0.00036635926
Sex Ratio	0.5874331229	0.00115467504
Daily specific fecundity	19.0353114374	
Number of Sets	30	

CORRELATIONS

Parameter	W	F	S	R
Whole - Body Weight (W)		0.98160171	-0.4288243	0.07873889
Batch Fecundity (F)			-0.3770331	0.03661725
Fraction Spawning (S)				-0.1127607
Sex Ratio (R)				

[a] Area of Region 1 is 41,878 km^2, Region 2 DEPM area is 272,603 km^2, and the DEPM area is 314,481 km^2

Table 6. The spawning biomass related parameters: daily egg production/0.05m^2 (P_0),daily mortality rate (z), survey area (km^2), two daily specific fecundities: (RSF/W), and (SF/W); s. biomass, female spawning biomass, total egg production (TEP) and sea surface temperature for 1986, 1987, 1994, 2004, 2005 and 2007-2011

Calendar year	Season	Region	[1]P_0/0.05m^2 (cv)	Z (CV)	[2]RSF/W based on S_1	[3]RSF/W based on S_{12}	[3]FS/W based on S_{12}	[4]Area (km^2)	[5]S. biomass (cv)	S. biomass females (cv)	S. biomass females (Sum of R1andR2) (cv)	Total egg production (TEP)	Mean temper-ature (°C) for positive eggs	Mean temper-ature (°C) from Calvet
1986(Aug)	1986	[6]S	1.48(1)	1.59(0.5)	38.31	43.96	72.84	6478	4362 (1.00)	2632 (1)		9587.44		
		N	0.32(0.25)		8.9	13.34	23.89	5333	2558 (0.33)	1429 (0.28)		1706.56		
		whole	0.95(0.84)		23.61	29.89	49.97	11811	7767 (0.87)	4491 (0.86)	4061 (0.66)	11220.45	18.7	18.5
1987 (July)	1987	1	1.11(0.51)	0.66(0.4)	38.79	37.86	57.05	22259	13050 (0.58)	8661 (0.56)		24707.49		
		2	0					15443	0	0		0		
		whole	0.66(0.51)		38.79	37.86	57.05	37702	13143 (0.58)	8723 (0.56)	8661 (0.56)	25637.36	18.9	18.1
1994	1993	1	0.42(0.21)	0.12(0.91)	11.57	11.42	21.27	174880	128664 (0.30)	69065 (0.30)		73449.6		
		2	0(0)	-				205295	0	0		0		
		whole	0.193(0.21)		11.57	11.42	21.27	380175	128531 (0.31)	68994 (0.30)	69065 (0.30)	73373.775	14.3	14.7
2004	2003	1	3.92(0.23)	0.25(0.04)	27.03	26.2	42.37	68204	204118 (0.27)	126209 (0.26)		267359.68		
		2	0.16(0.43)		-	-	-	252416	30833 (0.45)	19065 (0.44)		40386.56		
		whole	0.96(0.24)		27.03	26.2	42.37	320620	234958 (0.28)	145297 (0.27)	145274 (0.23)	307795.2	13.4	13.7
2005	2004	1	8.14(0.4)	0.58(0.2)	31.49	25.6	46.52	46203	293863 (0.45)	161685 (0.42)		376092.42		
		2	0.53(0.69)		3.76	3.2	7.37	207417	686168 (0.86)	298258 (0.89)		109931.01		
		whole	1.92(0.42)		15.67	12.89	27.11	253620	755657 (0.52)	359209 (0.50)	459943 (0.60)	486950.4	14.21	14.1
2007	2006	1	1.32(0.2)	0.13(0.36)	12.06	13.37	27.54	142403	281128 (0.42)	136485 (0.36)		187971.96		
		2	0.56(0.46)		24.48	23.41	38.94	213756	102998 (0.67)	61919 (0.62)		119703.36		
		whole	0.86(0.26)		15.68	16.17	31.52	356159	380601 (0.39)	195279 (0.36)	198404 (0.31)	306296.74	13.7	13.6
2008	2007	1	1.45(0.18)	0.13(0.29)	57.4	53.89	68.54	53514	29798 (0.20)	22642 (0.19)		77595.3		
		2	0.202(0.32)		13.84	12.6	22.57	244435	78359 (0.45)	43753 (0.42)		49375.87		
		whole	0.43(0.21)		21.82	20.31	32.2	297949	126148 (0.40)	79576 (0.35)	66395 (0.28)	128118.07	13.1	13.1
2009	2008	1	1.76(0.22)	0.25(0.19)	19.50	20.37	36.12	74966	129520 (0.31)	73048 (0.29)		131940.16		
		2	0.15(0.27)		14.25	14.34	22.97	199929	41816 (0.38)	26114 (0.38)		29989.35		
		whole	0.59(0.22)		17.01	17.53	29.11	274895	185084 (0.28)	111444 (0.27)	99162 (0.24)	162188.05	13.6	13.5
2010	2009	1	1.70(0.22)	0.33(0.23)	21.08	24.02	51.56	27462	38875 (0.44)	18111 (0.39)		46685.4		
		2	0.22(0.42)		14.55	16.20	26.65	244311	66345 (0.58)	40336 (0.58)		53748.42		
		whole	0.36(0.29)		16.08	18.07	31.49	271773	108280 (0.46)	62131 (0.46)	58447 (0.42)	97838.28	13.7	13.9
2011	2010	1	5.57(0.24)	0.51(0.14)	19.03	24.26	41.16	41878	192332 (0.31)	113340 (0.30)		233260.5		
		2	0.487(0.33)		11.40	14.67	25.04	272603	181016 (0.48)	106046 (0.49)		132757.7		
		whole	1.16(0.26)		14.85	19.04	32.40	314481	383286 (0.32)	225155 (0.32)	219386 (0.28)	364798.0	13.5	13.6

1: P_0 for the whole is the weighted average with area as the weight.

2. The estimates of adult parameters for the whole area were unstratified and RSF/W was based on original S_1 data of day-1 spawning females. For 2004, 27.03 was based on sex ratio= 0.618 while past 2007 biomass used RSF/W of 21.86 based on sex ratio = 0.5.(Lo et al. 2008)

3. The estimates of adult parameters for the whole area were unstratified. Batch fecundity was estimated with error term. For 1987 and 1994, estimates were based on S_1 using data of day-1 spawning females. For 2004, all trawls were in region 1 and value was applied to region 2,

4. Region 1, since 1997, is the area where the eggs/min from CUFES $\geq$1 and prior to 1997, is the area where the eggs/0.05m^2 >0 from CalVET tows

5: For the spawning biomasses, the estimates for the whole area uses unstratified adult parameters

6. Within southern and northern area, the survey area was stratified as Region 1 (eggs/0.05m2>0 with embedded zero) and Region 2 (zero eggs)

Table 7. Temperature range (3m depth) and presence (+) of Pacific sardine eggs collected in CUFES samples and adults taken in trawls during the spring 2006, 2008, and 2010 surveys off the west coast of the United States.

Survey Information	**April 2006**	**April 2008**	**April 2010**	**April 2011**
Washington – Oregon: 48.5° – 42°N				
Sea Temperature Range	9.1-11.8°C	8.2-10.1 °C	9.5-11.4°C	9.4-9.5
Mean °C of sardine positive trawls	na	na	na	9.4
Number positive trawls (total)	0 (9)	0 (25)	0 (12)	1 (5)
Number of sardine sampled	-	-	-	2
Mean body weight (g)	-	-	-	31g
Eggs, Region 1	+	-	-	-
Eggs, Region 2	+	-	-	-
Northern California: 42°N – CalCOFI line 60				
Sea Temperature Range	10.8-12.2°C	7.8-11.6°C *	9.6-13.2°C	-
Mean °C of sardine positive trawls	11.4°C	11.5°C	13.2°C	-
Number positive trawls (total)	3 (4)	1 (15)	1 (17)	0
Number of sardine sampled	101	1	50	-
Mean body weight (g)	91g	148g	152g	-
Eggs, Region 1	+	-	-	-
Eggs, Region 2	+	+	+	-
standard DEPM: CalCOFI lines 60 – 95 (San Francisco – San Diego)				
Sea Temperature Range	13.3-16.6°C	11.2-15.5°C	12.1-15.9°C	9.9-16.3°C
Mean °C of sardine positive trawls	14.4°C	12.4°C	13.6°C	13.1°C
Number positive trawls (total)	7 (22)	12 (31)	18 (68)	36 (100)
Number of sardine sampled	194	353	635	666
Mean body weight (g)	67g	105g	127g	108g
Eggs, Region 1 (area, km^2)	+ (98034)	+ (53514)	+ (27462)	+ (41878)
Eggs, Region 2	+	+	+	+
Whole DEPM area P_0	1.96	0.43	0.36	1.16

* a single negative offshore trawl at 38.4°N recorded 13.2°C

Table 8. Pacific sardine female adult parameters for surveys conducted in the standard daily egg production method (DEPM) sampling area off California (1994 includes females from off Mexico).

		1994	1997	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011
Midpoint date of trawl survey		22-Apr	25-Mar	1-May	21-Apr	25-Apr	13-Apr	2-May	24-Apr	16-Apr	27-Apr	20-Apr	8-Apr
Beginning and ending dates of positive collections		04/15-05/07	03/12-04/06	05/01-05/02	04/18-04/23	04/22-04/27	03/31-04/24	05/01-05/07	04/19-04/30	04/13-04/27	04/17-05/06	04/12-04/27	03/23-04/25
N collections with mature females		37	4	2	6	16	14	7	14	12	29	17	30
N collection within Region 1		19	4	2	6	16	6	2	8	4	15	3	14
Average surface temperature (°C) at collection locations		14.36	14.28	12.95	12.75	13.59	14.18	14.43	13.3	12.4	12.93	13.62	13.12
Female fraction by weight	R	0.538	0.592	0.677	0.385	0.618	0.469	0.451	0.515	0.631	0.602	0.574	0.587
Average mature female weight (grams): with ovary	W_f	82.53	127.76	79.08	159.25	166.99	65.34	67.41	81.62	102.21	112.40	129.51	127.59
without ovary	W_{of}	79.33	119.64	75.17	147.86	156.29	63.11	64.32	77.93	97.67	106.93	121.34	119.38
Average batch fecundity[a] (mature females, oocytes estimated)	F	24283	42002	22456	54403	55711	17662	18474	21760	29802	29790	39304	38369
Relative batch fecundity (oocytes/g)		294	329	284	342	334	270	274	267	292	265	303	301
N mature females analyzed		583	77	9	23	290	175	86	203	187	467	313	244
N active mature females		327	77	9	23	290	148	72	187	177	463	310	244
Spawning fraction of mature females[b]	S	0.074	0.133	0.111	0.174	0.131	0.124	0.0698	0.114	0.1186	0.1098	0.1038	0.1078
Spawning fraction of active females[c]	S_a	0.131	0.133	0.111	0.174	0.131	0.155	0.083	0.134	0.1187	0.1108	0.1048	0.1078
Daily specific fecundity	$\frac{RSF}{W}$	11.7	25.94	21.3	22.91	27.04	15.67	8.62	15.68	21.82	17.53	18.07	19.04

[a] 1994-2001 estimates were calculated using $F_b = -10858 + 439.53\ W_{of}$ (Macewicz et al. 1996), 2004 used $F_b = 356.46W_{of}$. (Lo and Macewicz 2004), 2005 used $F_b = -6085 + 376.28\ W_{of}$ (Lo and Macewicz 2006), 2006 used $F_b = -396 + 293.39\ W_{of}$ (Lo et al. 2007a); 2007 used $F_b = 279.23W_{of}$ (Lo et al. 2007b), 2008 used $F_b = 305.14W_{of}$ (Lo et al. 2008), 2009 used $F_b = -4598 + 326.78W_{of} + e$ (Lo et al. 2009), and 2010 used $F_b = 5136 + 287.37W_{of} + e$ (Lo et al. 2010b).

[b] Mature females include females that are active and those that are postbreeding (incapable of further spawning this season). S_1 was used for years prior to 2009 and S_{12} was used staring in 2009.

[c] Active mature females are capable of spawning and have ovaries containing oocytes with yolk or postovulatory follicles less than 60 hours old.

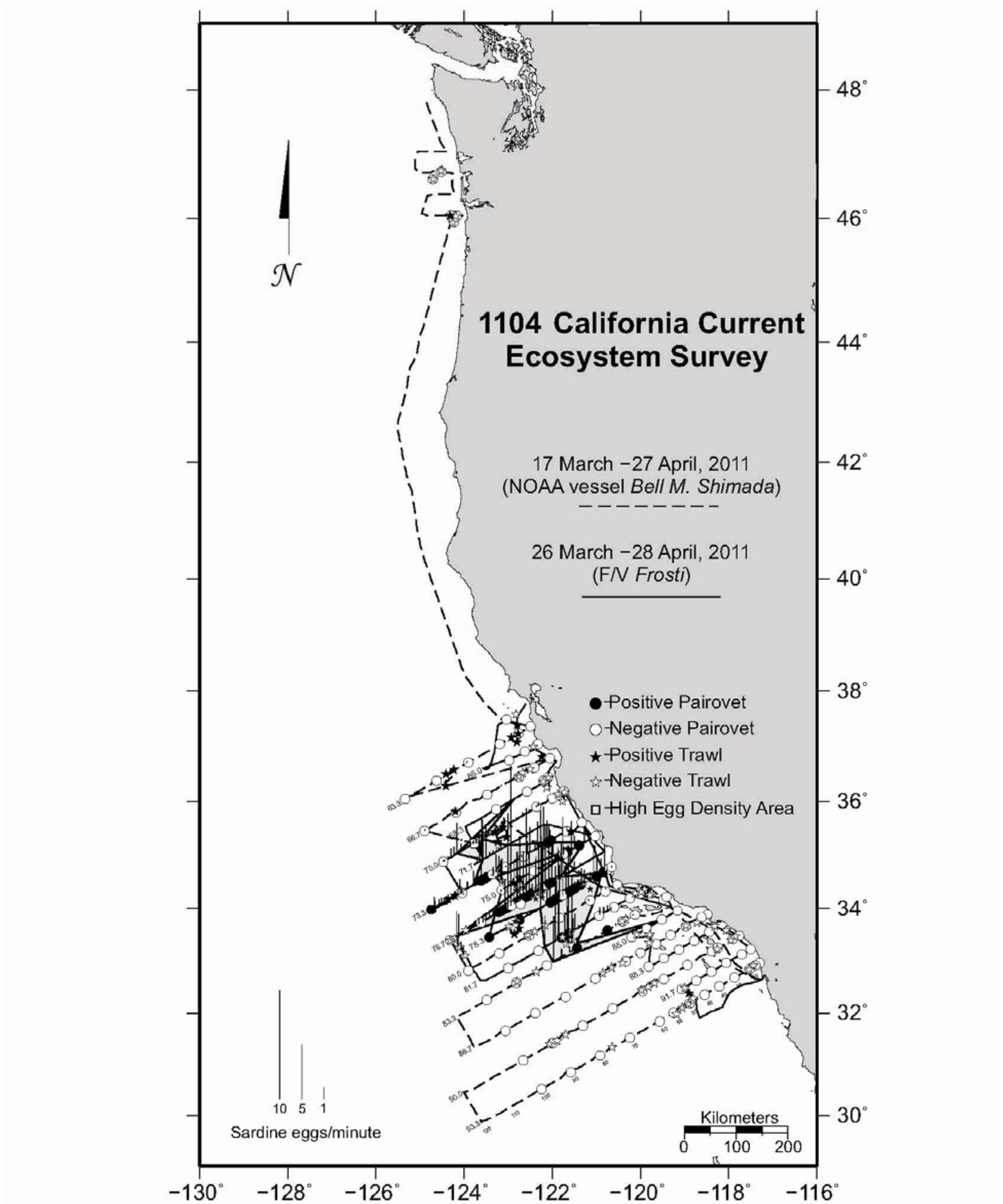

Figure 1. Location of sardine eggs collected from CalVET, a.k.a. Pairovet; (solid circle is a positive catch and open circle is zero catch) and from CUFES (stick denotes positive collection), and trawl locations (solid star is catch with sardine adults and open star is catch without sardines) during the 2011 survey aboard two vessels: F/V *Frosti* (solid line) and R/V *Shimada* (dash line). Shaded area is Region 1, the high egg-density area, and the rest of survey area is Region 2.

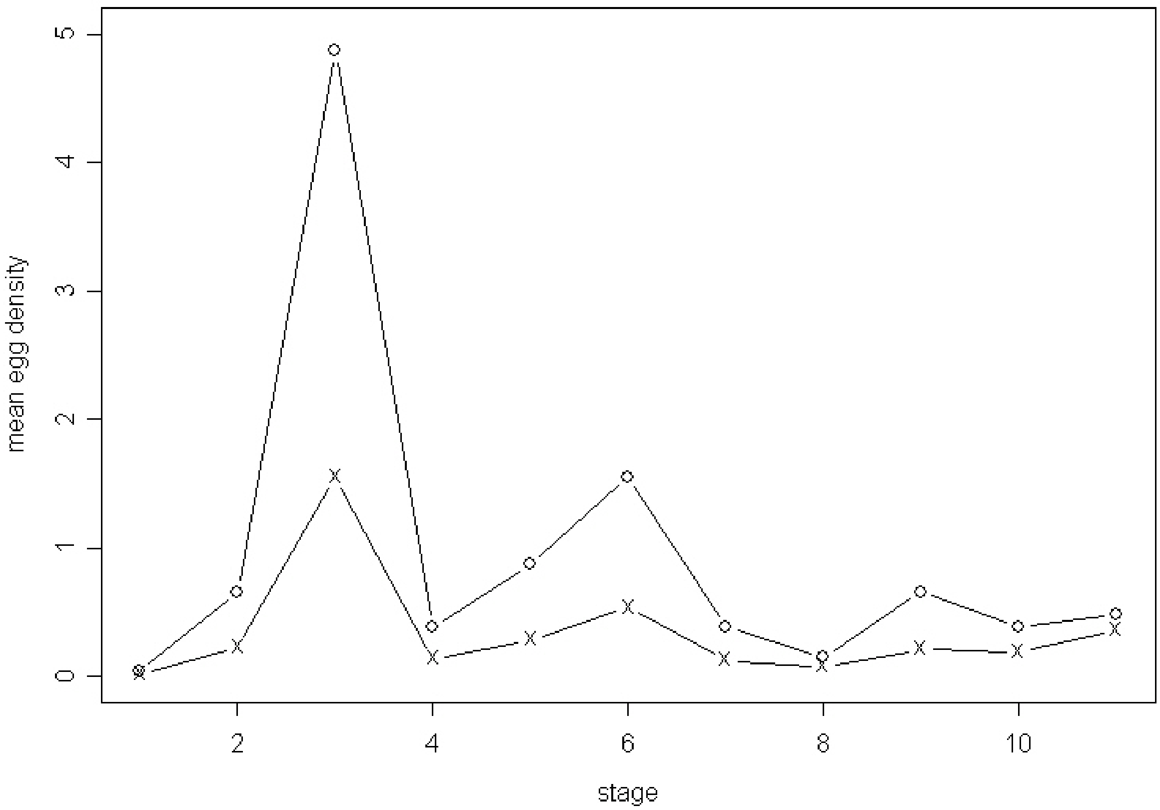

Figure 2. Mean sardine egg density (eggs per 0.05 m^2) for each developmental stage within each area for April 2011. Symbols: o = Region 1 and x = DEPM survey area (CalCOFI line 95 to 60).

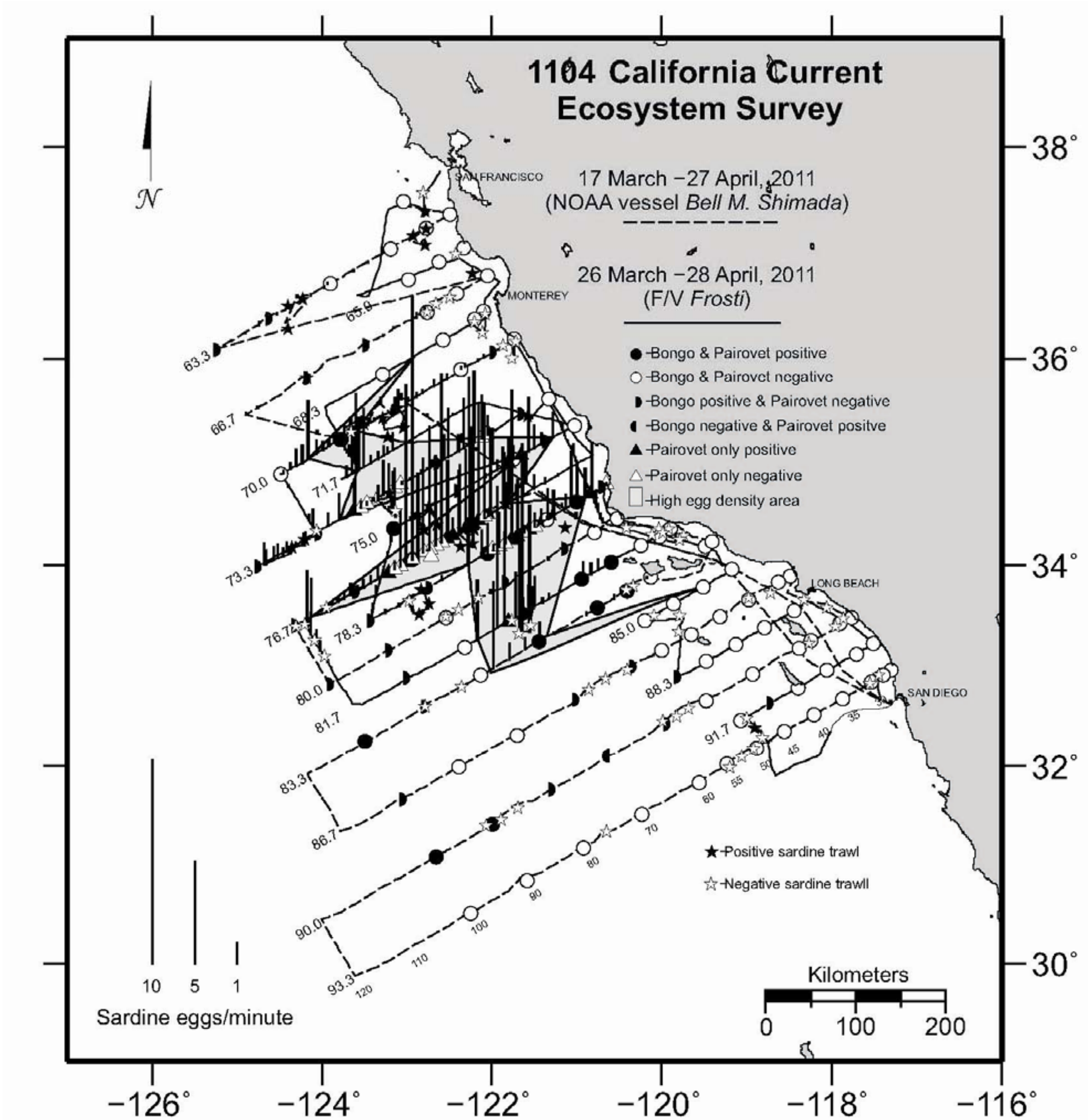

Figure 3. Location of sardine trawls (star), yolk-sac larvae collected from CalVET (or Pairovet; circle and triangle) and from Bongo (circle and square) during the 2011 survey aboard two vessels: F/V *Frosti* (solid line) and R/V *Shimada* (dash line). Solid symbols are positive and open symbols are zero catch. Few yolk-sac larvae were caught north of CalCOFI line 60.0. The shaded area is Region 1: the high egg-density area. Region 2 in the standard DEPM area includes the rest of the survey area shown between CalCOFI line 95.0 and 60.0.

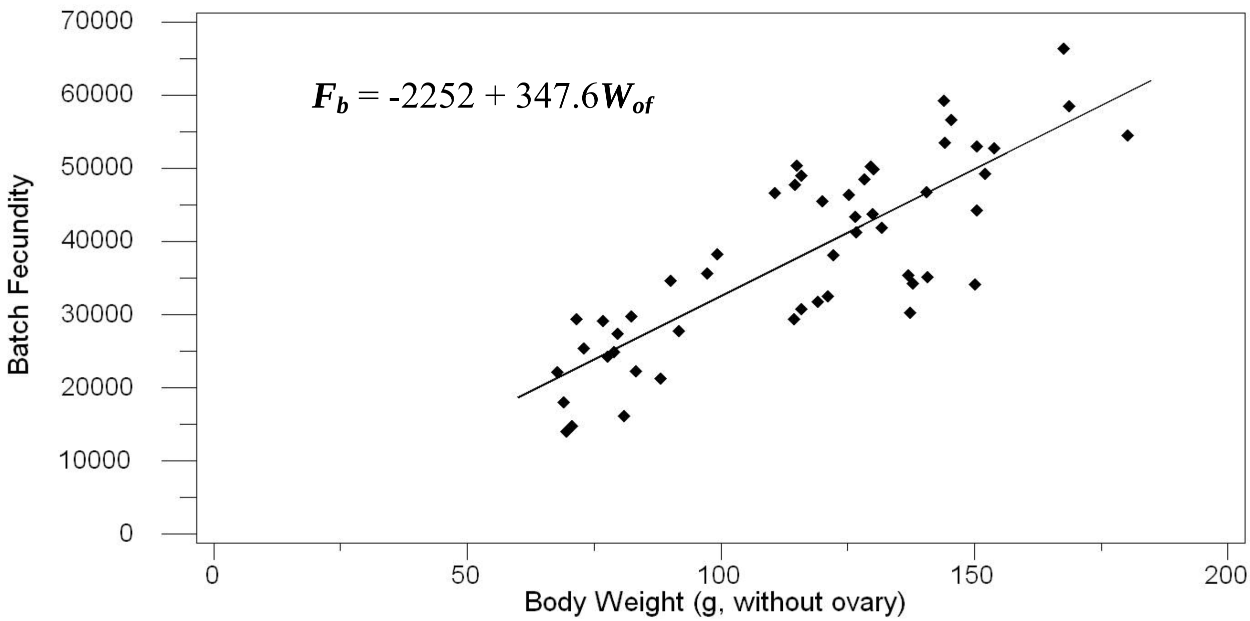

Figure 4. Batch fecundity (F_b) of *Sardinops sagax* as a function of female body weight (W_{of}, without the ovary) for 52 females taken onboard the *Shimada* and *Frosti* during April 2011. The batch was estimated from the number of hydrated or migratory-nucleus-stage oocytes.

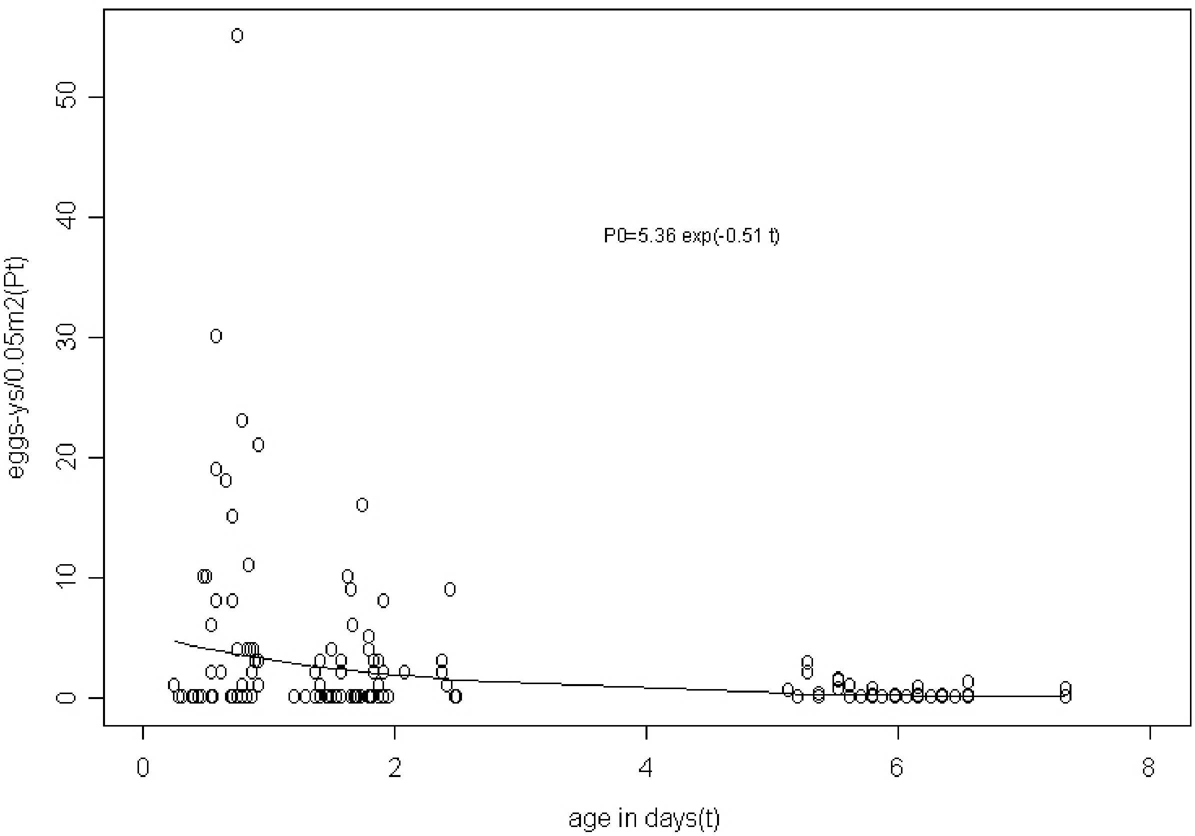

Figure 5. Embryonic mortality curve of Pacific sardines. Staged egg data were from CalVET and yolk-sac larval data were from CalVET and Bongo during April 2011, onboard *Shimada* and *Frosti*. The number, 5.36, is the estimate of daily egg production at age 0 (P_0) before correction for bias.

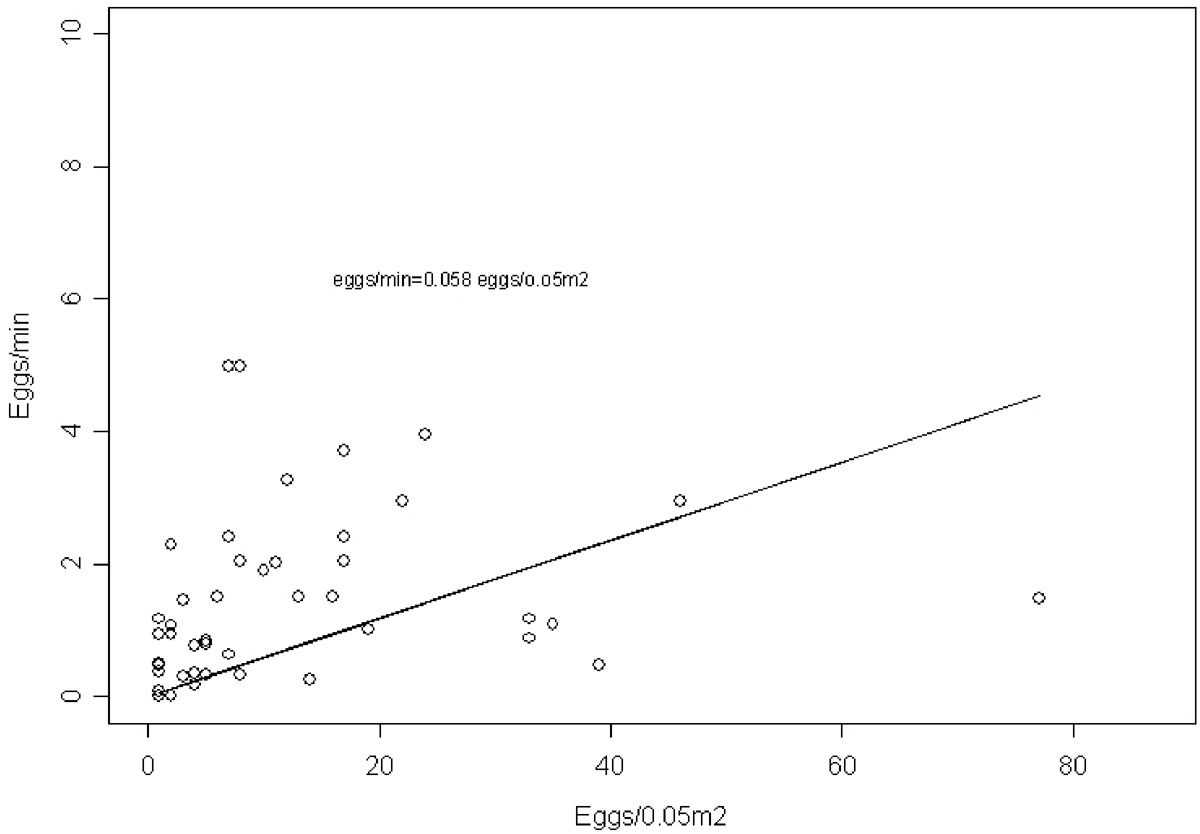

Figure 6. Catch ratio of eggs/min from CUFES to eggs/0.05m^2 from CalVET during April 2011 from *Frosti* and *Shimada* collections.

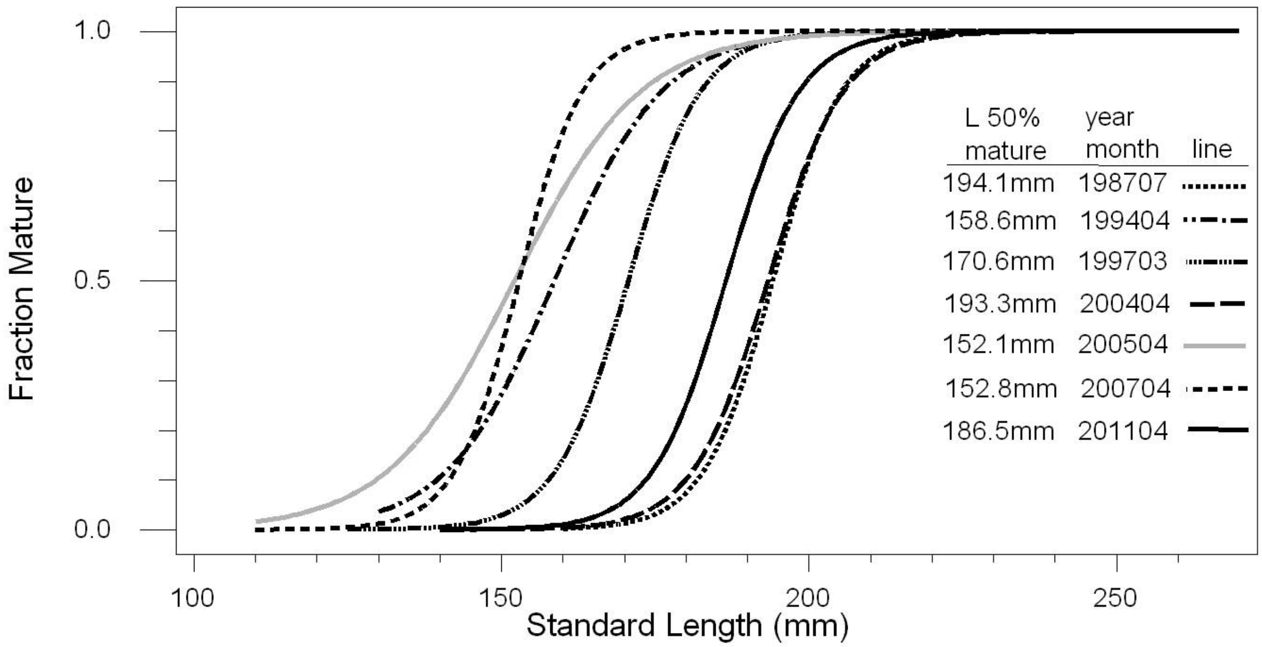

Figure 7. Fraction of Pacific sardine females randomly sampled during seven DEPM sardine surveys that were sexually mature as a function of standard length. The length at 50% maturity from the April 2011 survey was the third largest at 186.5 mm. Insufficient immature females were collected during 2002, 2008, 2009, and 2010 DEPM surveys to calculate length at 50% mature.

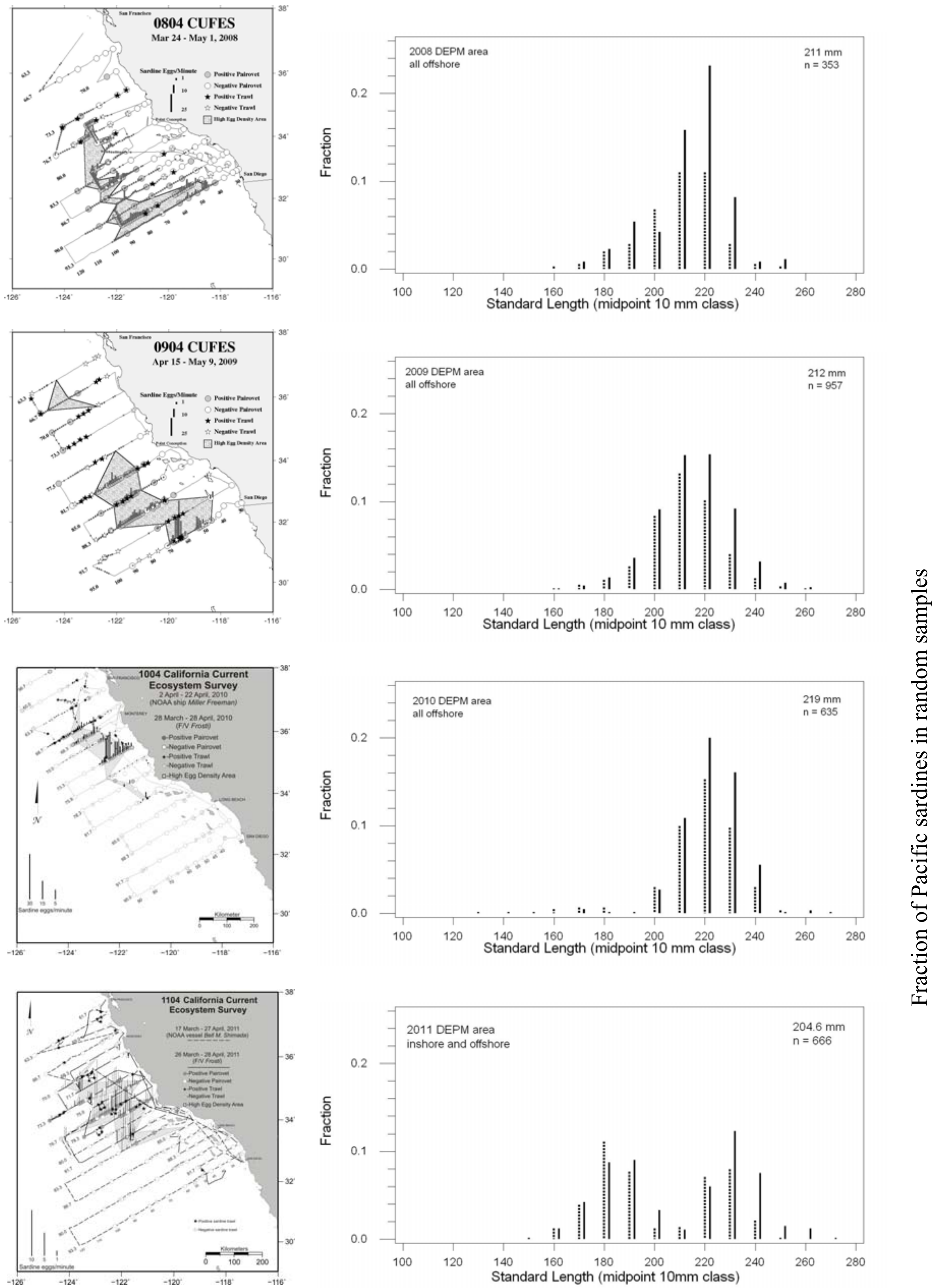

Figure 8. Trawl-egg map, length distribution and mean length of Pacific sardines caught in the 2008, 2009, 2010, and 2011 DEPM survey areas. Males indicated by dotted bars and females by solid bar.

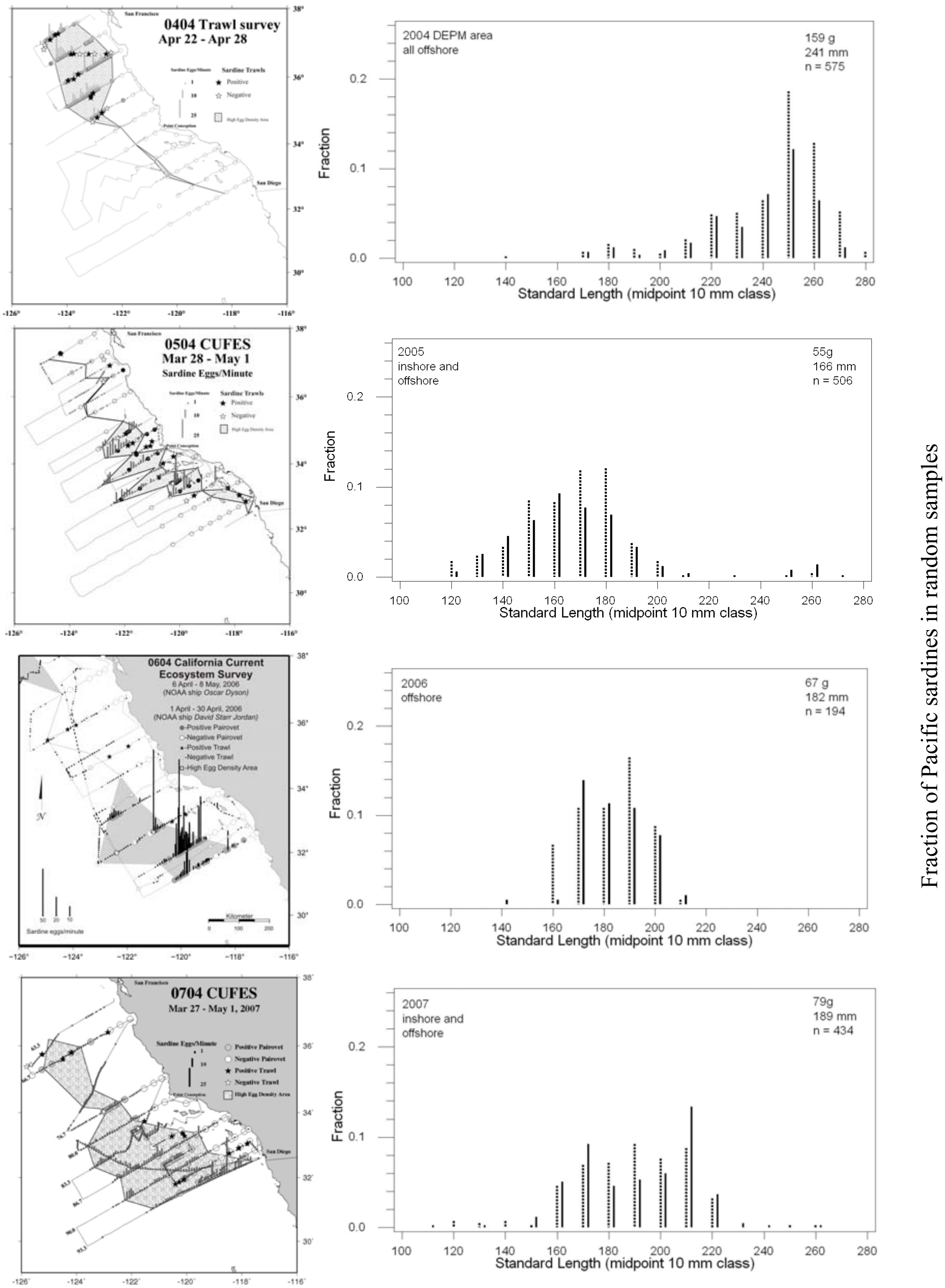

Figure 9. Trawl-egg map, length distribution and mean length and weight of Pacific sardines caught in the 2004, 2005, 2006 and 2007 DEPM survey areas. Males indicated by dotted bars and females by solid bar.